

## **PROJECT SOLVE: Web-based Guided Practice to Improve Math Word Problem Solving**

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### **Introduction**

PROJECT SOLVE addresses, in an innovative and practical way, a critical problem facing most deaf college students and other learners with special needs – inadequate preparation and practice in problem solving and analytical thinking. Supported by a grant from the Fund for the Improvement of Postsecondary Education (FIPSE), U.S. Department of Education, PROJECT SOLVE will provide web-based problem-solving instruction and guided practice for math word problems. While deaf college students are the primary audience, this project has clear implications for other college students for whom reading and math word problem solving is difficult, especially Learning Disabled (LD) students. This project also has instructional implications for high school students who are college bound, and who face similar difficulties with reading comprehension, problem-solving logic, and organization.

PROJECT SOLVE offers college and high school teachers a platform to provide deaf and LD students independent assignments for practicing and improving their analytical thinking and problem solving skills without restructuring their courses. The web site will provide a range and variety of word problems presented in language typically found in college math courses. An optional help menu will provide clear concise written and graphic information to guide students with a range of reading abilities (8<sup>th</sup>-12<sup>th</sup> grade) through each math word problem. Thus, while deaf and LD students are challenged with solving high school and college level math word problems, they will have readable guidance help options at their ability levels. This web program will be available daily on a 24-hour basis, giving students independent, unrestricted access to problem-solving instruction and guided practice. The primary goals for PROJECT SOLVE are:

- 1) To develop an asynchronous web site providing guided practice and instruction for math word problem solving to deaf college and high school students.
- 2) To evaluate the overall effectiveness of the web site as a practical on-line problem solving resource in the education of deaf students.
- 3) To disseminate widely the problem solving web site resources, including information to enhance pre-service and in-service teacher education for grades 9-12 programs.
- 4) To evaluate the effectiveness of the problem solving web site with LD students having learning disabilities for reading and math, and to modify the web site as appropriate.

## **Why Problem Solving?**

Polson and Jeffries (1985), contend there is “general agreement that the educational system as currently constituted does not successfully teach general problem-solving skills to a majority of its graduates” (p. 417). Others suggest the gap between theory and practice exists because students are not taught general problem-solving skills (Glover, Ronning, & Bruning, 1990). These findings are also true for deaf learners, whose K-12 teachers are often poorly prepared to teach mathematics (Pagliaro, 1998). When these students arrive at postsecondary programs, they generally demonstrate inadequate word problem-solving skills.

The ability to solve word problems is a critical skill applicable to many kinds of problem solving because the component skills are important to the process of constructing representations of complex situations (Briars & Larkin, 1984). Among the organizations emphasizing the importance of developing word problem skills is the National Council of Teachers of Mathematics (NCTM) whose national standards state that “. . .problem solving is much more than applying specific techniques to the solution of classes of word problems. It is a process by which the fabric of mathematics . . . is both constructed and reinforced” (1989, p. 1). The new revised NCTM Standards 2000 continue the emphasis and importance on helping students become flexible and resourceful problem solvers.

Deaf College Students: There has been a steady increase in the number of deaf college students, with more than 25,000 now enrolled in over 2,500 postsecondary institutions across the country (Rodriguez, 2000; National Center for Education Statistics, 1994). College students who are deaf have needs similar to all college students regarding the development of good problem-solving skills. Problem-solving skills are critically important to both their learning in college and their future careers. Their special difficulties in solving word problems are related to poor reading comprehension (Pau, 1995), lack of reflective behavior, lack of persistence in working through difficult problems, difficulty in transferring learning from one context to another, and in remembering what has been learned (Glennon, 1981, p. 336). Only 6% of deaf people at 18 years of age read at the same level as an average hearing reader of the same age (Center for Assessment & Demographic Studies, 1991). Allen (1994) estimated that only 8% of all deaf students enrolled in college read at the 8<sup>th</sup> grade level or higher. However, recent research has shown that deaf college students can improve their problem-solving performance with strategy instruction (Mousley & Kelly, 1998).

The need for deaf students to improve problem solving skills has consistently been recognized by educators (Williams & Kubis, 1982; Daniele, 1993; Pagliaro, 1998). Traditionally, these students have been educated with an emphasis on drill and practice, and have not developed the critical thinking skills needed for application in real problem solving situations. Furthermore, the reading statistics cited above suggests that many deaf students may have insufficient preparation to either fully benefit from a college education, or to subsequently compete for career opportunities on an equal basis with other typical college graduates.

Woditsch (1991) identifies five generic thinking skills exhibited by capable, confident analytical thinkers that are important to successful problem solving. These skills include selective attention, sustained analysis, analogizing, suspension of closure, and autocensorship. Through these generic thinking skills, “good problem solvers” give conscious, focused, and undivided attention to a problem. They persist in considering all relevant information and use analogies to relate known information to better understand new problem situations. They assess all available problem information before arriving at a conclusion. And finally, they test or evaluate their potential solution covertly, before affirmation.

A review of the literature indicates that deaf students have not consistently demonstrated such skills. Lack of reflective thinking, for example, has been documented by a number of researchers (Altshuler, Deming, Vollenweider, Rainer, & Tandler, 1976; Meadow & Schlesinger, 1971; Meadow & Trybus, 1979). Glennon (1981) cites evidence showing that such a lack of reflective behavior may relate to low persistence in working through difficult problems. Glennon’s investigation also summarized studies showing that deaf students have difficulty in transferring learning from one context to another, as well as in remembering what has been learned.

While deaf students’ difficulty with word problems may be attributed, in part, to reading comprehension (Kelly & Mousley, 1999), other factors amenable to instruction and practice are also involved. Kelly and Mousley (in progress) provide evidence that suggests deaf college students’ difficulties with solving word problems may result from poor focus affecting their self-monitoring and accuracy in performing calculations. Their work shows promise that a system of guided practice offered across the country could have a positive impact on the development of critical thinking and problem solving skills of deaf learners. There is a critical need for such a consistent, comprehensive mentoring system for deaf college students to be available on a national basis. PROJECT SOLVE addresses this need through asynchronous (accessible any time, from anywhere) guided learning activities for problem solving provided through the World Wide Web.

Other Target Audiences: There is the expectation that all students bring problem solving skills, or the foundations for such skills, to their postsecondary experience. Like deaf students, Learning Disabled (LD) students struggle with comprehension and retention of text material, especially with word problems, and difficulties recalling and applying what has been taught (Bucknell University, January 12, 2001). Students with learning disabilities also have difficulties dealing with multiple variables and accurately solving problems involving multiple steps. Special needs students face further complications because college teachers are generally not trained with regard to the educational implications of either hearing loss or learning disabilities. LD student enrollments have shown steady growth from 1988 when they represented 15% of the entering freshman students with disabilities to 32% of the freshman with disabilities in 1994 (Henderson, 1995). The growing presence of these students has increased the need to implement innovative instruction, tutoring and assistance.

### **What PROJECT SOLVE Offers to Students and Teachers**

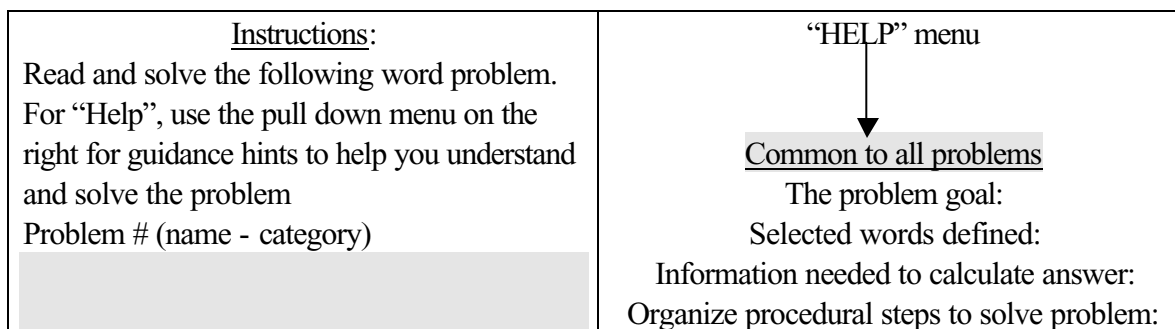
This web-based problem-solving project is different from other math reform projects in a number of ways. 1) While other projects have often provided new instructional directions, or established standards

and practices that teachers must implement, PROJECT SOLVE will provide a practical operational instructional avenue by which the students can improve their word problem-solving skills through practice combined with guidance and feedback. Importantly, the design of the guided instruction will be based on a thorough review of linguistic and cognitive research findings indicating specific needs of the target learners. 2) The guided practice environment is not dependent on the schedule of tutors and school instruction. Thus, students will have a readily accessible independent learning option. 3) The project materials can be used by teachers to complement their teaching with minimal preparation, or can be independently accessed by student initiative. 4) This project will provide practice with both problem-solving exercises (a well-defined problem with one clearly correct answer) and true problem-solving situations (less well defined, requiring more effort to understand and accurately represent). 5) PROJECT SOLVE will collect data on the students' problem-solving performance, thus offering the potential to develop a database in a wide range of problem-solving situations. Other reform efforts have not offered this potential. 6) A long-term potential exists to expand to other student populations through web accessibility, the guided "help" menu, and multiple item pools of problems relevant to other target student populations at different ages and grade levels.

PROJECT SOLVE appears to be a unique web resource for deaf and LD students, as well as being distinct from other math web sites. Using the key search parameters of deaf, Learning Disabled, LD problem solving, word problem solving, and math word problem solving, no web urls were identified for LD students and only two for deaf students. One of these is PROJECT SOLVE, and the other is a Gallaudet University web page on developing general math skills, but it does not specifically focus on word problem solving. In addition, a broader web search was conducted using the search parameter of math tutoring which revealed approximately 153,000 entries pertinent to math tutoring. An examination of 300 entries showed that most of the entries were for paid individual tutoring services, specific college math center tutoring services, and commercial companies selling math publications and software.

**Design**

An *interactive Web page* design will provide students independent learning opportunities to practice and improve their analytical problem-solving skills with a wide variety of math word problems. Problem-specific instructional guidance via a "help" menu will give students instructional support in analyzing and solving the word problems. The "home" splash page of PROJECT SOLVE will have an introduction with appropriate informational links for both students and teachers, in addition to the guided practice environment for word problems, briefly illustrated in the accompanying graphic.



word problem inserted here	<u>Knowledge unique to this specific problem</u>
<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 0 auto;">Submit answer</div>	Graphic/visual representation: Reminder "how to _____": Other _____

On the PROJECT SOLVE "home" splash page, the menu bar at the top of the page will provide students and teachers links to the project description, staff, email communications, and information for teachers on how they can utilize this web site. Also, in the top menu bar are links to information and instruction for students pertinent to improving their problem solving skills, and a web environment for students to practice a variety of word problems with guidance options from a help menu. It will be refined and the functionality improved relative to the results of the ongoing student evaluation feedback, students' problem solving performance data from the controlled evaluation study, and field tested with both deaf and LD students at the college and high school level (grades 9-12). Design refinement of the web site will also take into consideration the suggestions of the advisory group, LD consultative guidance on students with reading and math disabilities, and the participating teachers' insights and feedback.

The teacher information page will provide informational links and guidance for how teachers can utilize this web site to improve their students' word problem solving skills. In addition, it will provide information on the distinctions between problem solving exercises and true problem solving situations. It will also give directions on how teachers can contribute to the item pools of the practice word problems. The goal of this approach is to assure a sufficient and increasingly wide selection of relevant and challenging math word problems in the web site item pool. In addition, teachers who contribute to the item pool for this problem solving web site will be more likely to have their students use the web site to independently practice their problem solving skills.

Existing web development software will create the components and functionality of this interactive web project containing text, graphics, and animation. It will be fully functional to anyone with access to the Internet through a web browser, with common plug-ins, on either Macintosh- or Windows-based computers. Existing spreadsheet software will be used to compile the confidential databases to evaluate the students' problem-solving improvement and the efficacy of the instruction.

Accessibility of the web site. Every effort will be made to assure that the web design of PROJECT SOLVE is in compliance with Section 508 of the Rehabilitation Act, §1194.22. Design guidelines for web accessibility will be sought from WebAim (Web Accessibility In Mind) at the Center for Persons with Disabilities at Utah State University < <http://www.webaim.org>>, as well as other Internet accessibility resources, such as Equal Access to Software and Information (EASI). The General Services Administration will also be used as a resource on web accessibility guidelines, where they provide a link to the "Top Ten Mistakes in Web Design" at [www.itpolicy.gsa.gov/cita/wpa.htm](http://www.itpolicy.gsa.gov/cita/wpa.htm).

### **Types of Problem Solving Practice**

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<http://www.rit.edu/~techsym>

Multiple resources and references will guide the type of word problems selected for the practice item pool of PROJECT SOLVE. These include 1) literature reviews on problem solving and math, 2) a national advisory group consisting of math educators, 3) math texts from high school and college courses, 4) teachers who are involved with the math instruction, and 5) NCTM Standards.

Generally, there is agreement that the best way to improve one's problem solving skills is to gain experience through practice with a variety of problem types (Glover, Ronning, & Bruning, 1990; Snowman & Biehler, 2000). Students need practice with problem exercises that require memory recall, and application of knowledge and formulae to solve the exercises. Importantly, they also need experience with "true problem solving" situations that cannot be solved by simply applying set procedures or algorithms. Problem exercises and true problem solving situations may be distinguished as follows.

- Exercises are problem tasks that the student knows appropriate solution procedures for, but has yet to become adept at applying these procedures or at matching these procedures to appropriate problems (Smith, 1991, p. 6), in other words, skill at translating from linguistic to algorithmic forms. These tasks can be solved by recognition, recall, and reproduction, and are easy, simple, familiar, and straight-forward to solve. Algorithms are "completely determined . . . ready-made prescriptions on how to act" (Landa, 1972), little more than 'black boxes' used to produce answers with little or no understanding (Lochhead & Collura, 1981).
- True problem solving involves tasks requiring analysis and reasoning toward a goal (or "solution"). This analysis must be based on an understanding of the domain from which the task is drawn. A "true problem" cannot merely be solved by recall, recognition, or reproduction. It requires skills in creativity in analysis and synthesis. Problem solving therefore becomes the process by which a system generates an acceptable solution to such a problem (Smith, 1991, p. 8). "Real problems" are hard, complex, unfamiliar, and perplexing.

These distinctions have been described by Hayes (1980, 1989) as well defined-versus ill-defined problems. Well-defined problems are those for which a clear-cut solution (goal state) is readily available (e.g., arithmetic, mathematics, and science problems are well-defined problems with one clearly correct goal state). Representations for well-defined problems are relatively easier for typical, trained students to generate and understand. In contrast, ill-defined problems are those we cannot solve without taking some action to further define them. Representations for ill-defined problems are more challenging and require considerably more effort to represent in new, unusual, and useful ways. Following are examples of both a problem exercise and a true problem solving situation:

Example of a problem exercise in mathematics (a well-defined problem with one clearly correct answer): The radius of a circle is 12.5 inches. Find the circumference of the circle.

Example of a true problem solving situation in mathematics (less well defined, requiring more effort to understand and represent in new and useful ways): Members of West High School band were hard at work practicing for the annual Homecoming parade. First they tried marching in rows of twelve, but Andrew was left marching alone. The band director was annoyed because it did not look good to have one row with only a single person in it, and, of course, Andrew wasn't happy either. To get rid

of this problem, the band director told the band members to march in columns of eight. But Andrew was still left to march alone. Even when the band marched in rows of three, Andrew was left to march alone. Finally, in exasperation, Andrew told the band director that they should march in rows of five in order to have all the rows filled. He was right. Now all the rows were filled and Andrew wasn't marching alone any more. Given that there were at least 45 musicians on the field but fewer than 200 musicians, how many students were there in the West High School Band (in Novick, 1988, adapted from a problem in Gardner, 1978)

Students need practice with both problem exercises and true problem solving situations. Problem exercises provide experience with reading and comprehending a problem, recognizing that it relates to knowledge and skill that one knows, and then applying the appropriate procedures to solve it. Knowledge and experience gained from problem exercises then can be used in part to solve true problem solving situations by subdividing and focusing on component parts of a perplexing problem that needs to be solved.

A true problem-solving situation should be within the mathematical and reading capabilities of apprentice problem solvers. Second, there should be a number of other analogous problem examples to provide practice and training. And third, there should be various ways to solve the problem (e.g., in the problem above, examining multiples of 12, of 5). These are examples of important principles that will guide the development of the PROJECT SOLVE web site.

In order to successfully practice solutions to a variety of problem situations, students need exposure to the general skills of problem identification and representation, information compilation, multiple methods of formulating solutions, and a systematic approach to the evaluation of their procedures and solutions (Snowman & Biehler, 2000). They also need practice with analogical reasoning to help them conceptualize new and unfamiliar problem solving situations (Glover, Ronning, & Bruning, 1990).

## **Evaluation**

The measurement of student learning outcomes as a result of their practice on this problem solving web site is an integral part of the proposed evaluation activities. Each student's performance with the practice problems and pre/post test problems will be saved to a confidential database for subsequent evaluation and analysis by the project staff. The project evaluation will involve two distinct components for assessing the outcomes of this web problem-solving project:

- 1) A controlled evaluation study will be conducted to a) evaluate the students' progress and improvement for solving word problems and b) to evaluate which guidance help is most beneficial to lower reading ability students as compared to higher reading ability students. To assure methodological control of the instructional variables under study, participating deaf and LD students will be selected from the student populations at RIT and from area high school programs.
- 2) A broader field implementation and evaluation study will be conducted to examine the utilization patterns and impact of this problem solving web site for deaf college and high school students

(grades 9-12) and LD college and high school students (grades 9-12). The analysis of the utilization patterns for the target populations will be examined and evaluated relative to the dissemination efforts planned and implemented for this project.

For the controlled evaluation and broader field implementation study efforts, all participating students' problem solving responses and related data for each practice problem will be recorded to a spreadsheet. The response data to be saved for analysis and evaluation are: 1) time spent solving problem; 2) "help" information access patterns; 3) number of trials needed to correctly solve problem, and 4) cumulative number and type of word problems they have solved to date. Differential patterns of "help" accessed by students at various reading and ability levels will be examined to identify each of the target student populations' unique support needs for problem solving. Also, these data will be used to evaluate student improvement in problem solving and more independent application of the problem-solving strategies. As "help" menu dependence decreases, corresponding decreases in total time spent solving problems and number of trials to success should occur.

Formative evaluation by students: To date, 18 deaf students have participated in individual intensive two-hour interviews about the feasibility of the prototype PROJECT SOLVE web site as a problem solving mentoring approach. This evaluation included Likert scales and related questions addressing various dimensions of the design of this prototype web site and the usefulness of such an internet-based project. The students were asked to solve three problems and every step of the problem solving was recorded in order to examine the data for patterns that may have implications for improvements in the web site design.

The student interviews validated the need for such a project. The evaluation included a range of students from Associate degree-level students undecided on a major to third-year mechanical engineering students. The three word problems selected were different in terms of the demands placed on their language and cognitive abilities. The evaluation data not only provided additional perspectives on the abilities and preferences of students as they approach problem solving, but also numerous suggestions for improving the design. Selected comments and suggestions resulting from the student interviews are provided below:

Student comments in response to whether they could learn from a web page like this:

- "Lots of things to choose from. I feel this is good. A human tutor can go off path a lot and not be accessible."
- "At first I felt awkward, but enjoyed it more after a few problems."
- "Yes, if exposed to some word problems I've not seen before. I was not familiar with problem #105 and it helped me."

Student design suggestions after they completed three problems on the web site:

- "Suggest trying to solve the problem first before going to help boxes."
- "A chat room for discussing problems with other students."
- "One help menu, not two."
- "Hold multiple help windows open."
- "More pictures, more clues, more formulas."



- “Ability to check my procedures instead of just being told my answer was incorrect.”

These one-on-one formative interviews confirmed the importance of evaluative feedback from the target student populations throughout the design and implementation of Project Solve.

The PROJECT SOLVE web site has been under development for approximately eight months. While the prototype design work has been completed, the refinement process continues regarding the functionality of the web site based on evaluative feedback to date and further literature reviews. Currently, new math word problems are being identified along with the related help guidance specific to each problem in order to increase the practice item pool to meet the needs of students. It is anticipated that the web site will be functional and accessible by November 2001.

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**Goals**

- Provide deaf students a word problem solving practice environment with guided help menu, available 24/7
- Develop a database for evaluation of students' progress and for research purposes focused on instruction
- Provide instruction and strategies for problem solving
- Provide teachers information and opportunities for using this problem solving web resource with their students
- Market and disseminate web site to relevant audiences for whom it has educational implications (deaf students in college, grades 6-12, LD students, etc.)

**DEFINITIONS OF A PROBLEM:**

A person is confronted with a problem when he wants something and does not know immediately what series of actions he can perform to get it (Newell & Simon, 1972, p. 72).

Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap, you have a problem (Hayes, 1980, p. i, 1989, p. xii).

**Typical errors in problem solving (Whimber & Lechhead, 1991)**

Inaccuracy in reading

- read too fast
- misread words
- did not reread

Inaccuracy in thinking

- preferred speed to accuracy
- not careful in performing operations or observing
- not consistent in interpreting words
- inaccurate in describing or visualizing a relationship

Not active in problem analysis:

- did not break problem into parts
- did not draw upon prior knowledge
- skipped unfamiliar words or phrases, and was satisfied with vague understanding of them
- did not translate unclear words or phrases into own words
- did not use the dictionary when necessary
- did not construct a representation (either mentally or on paper)
- did not evaluate attempt at solution or interpretation in terms of its reasonableness

Lack of perseverance

- little attempt to reason
- chose an answer base on only a superficial consideration of the problem
- approached problem in mechanical manner
- reasoned part of the problem, then jumped to conclusion

Typical errors in problem solving	Hearing Ss	Deaf Ss
Inaccuracy in reading	X	X
Inaccuracy in thinking	X	X
Not active in problem analysis	X	X
Lack of persistence	X	X

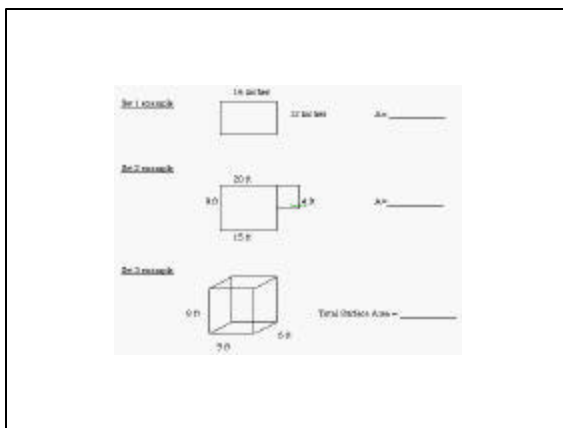
  

Math word problem solving obstacles associated with deaf students		
Reading comprehension (grammar, syntax, technical words, etc.)		X
Goal monitoring (leaving out steps)		X
Language-related reversals		X
Accuracy in calculation	(X7)	X
Difficulty in transferring learning from one context to another	X	X

From Kelly & Mousley (2001) Solving word problems: More than reading issues for deaf students. *American Annals of the Deaf*, July issue.

Table 3  
Mean scores with standard deviations in percentages of deaf and hearing students for solving 15 math word problems presented in grade/intermediate format

Group	Set 1 = 5 math	Set 2 = 5 math	Set 3 = 5 math	Total = 15 math
Deaf students Low < 7th reading level (n = 11)	5.8 (0.8)	5.8 (1.84)	2.7 (1.62)	11.3 (1.75)
High < 6th reading level (n = 11)	5.8 (0.8)	5.5 (1.13)	2.5 (1.37)	11.9 (2.32)
High < 5th reading level (n = 11)	4.8 (1.0)	4.1 (1.82)	2.4 (1.82)	11.3 (1.92)
Hearing students (n = 11)	5.8 (0.8)	4.2 (1.36)	3.9 (1.04)	11.1 (1.30)

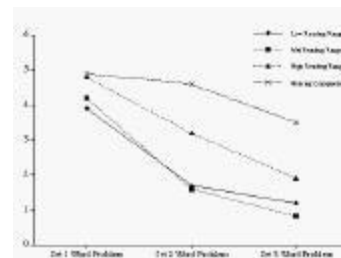


### Parallel word problem examples

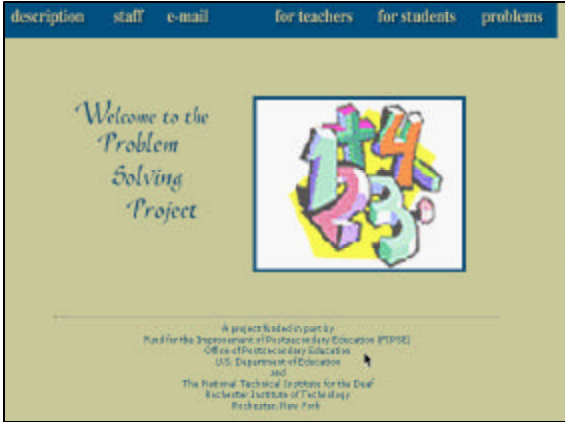
- **Set 1 example:** A rectangle measures 9 ft by 1.5 ft. What is the area of the rectangle?
- **Set 2 example:** A room measures 10 feet in length and 8 feet in width, with a closet that measures 2 feet by 4 feet. What is the total floor area of the room and closet?
- **Set 3 example:** A box measures 18 inches in width, 20 inches in length, and 8 inches in height. What is the total outer surface area of the box?

Table 4  
Mean scores with standard deviations in percentages of deaf and hearing students for solving 15 math word problems presented in word problems format that contained no the associated/related problem

Group	Set 1 = 5 math	Set 2 = 5 math	Set 3 = 5 math	Total = 15 math
Deaf students Low < 7th reading level (n = 11)	2.9 (1.81)	1.7 (1.35)	1.2 (1.05)	5.8 (2.14)
High < 6th reading level (n = 11)	4.2 (1.45)	1.6 (1.57)	.8 (1.25)	6.6 (1.44)
High < 5th reading level (n = 11)	4.0 (1.41)	2.2 (1.42)	1.2 (1.46)	7.4 (2.47)
Hearing students (n = 11)	4.9 (1.32)	4.0 (1.51)	3.0 (1.04)	11.9 (1.07)



- What the literature suggests for good problem solving:
- **General problem solving strategies for comprehension** (i.e., identifying the problem goal, looking up unfamiliar words, identifying key information needed to solve problem, and procedurally organizing the information for calculation)
  - **Applying learned knowledge to problem situations**
  - **Practice in representing different problem situations**
  - **Practice with a variety of problem situations in increasing difficulty**
  - **Practice with problem exercises and true problem solving situations**
  - **Evaluating one's procedures and answers for reasonableness**
  - **Developing depth and breadth in content domains**



- Review of math texts, college entrance exams and other references
- Harshbarger, R. J., & Reynolds, J. J. (2000). *Mathematical applications for the management, life, and social sciences* (6th ed.). Boston, MA: Houghton Mifflin Company.
  - Kohn, E. (1995). *Cliffs quick review: Algebra II*. Lincoln, NE: Cliffs Notes Incorporated.
  - Larson, R., & Hostetler, R. P. (2001). *Algebra and trigonometry* (5th ed.). Boston, MA: Houghton Mifflin Company.
  - Spiegel, M. R., & Moyer, R. E. (1998). *Schaum's outline of theory and problems of college algebra* (2nd ed.). New York: McGraw-Hill.
  - ACT college entrance exam
  - SAT college entrance exam



The prototype for the PROJECT SOLVE web site is currently undergoing revision and refinement.

It is anticipated that the PROJECT SOLVE web site will be available for use by November 2001

**PROJECT SOLVE url and e-mail**

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