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MICROCOMPUTER DEMONSTRATION EXERCISES FOR A COURSE ON CREATIVITY AND PROBLEM SOLVING

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ABSTRACT

In the context of an applied psychology course on thinking" designed for management and engineering students, four programs for personal computers on campus nave been developed that (I) present various types of puzzles and problems discussed in the course, (2) display the changing elements of the problem 35 the student works on it, and (3) collect various types of behavioral data on the student's problem solving activity, these puzzles and problems *11 involve "convergent" thinking (focused deduction or induction) and two 3 is to require creativity (or "divergent" thinking) in the sense of requiring flexibility of approach or method in order to achieve an efficient solution. Two of these programs have already seen usage in the course, and this paper describes those two 39 well as the data collected through their use and the teaching points aide for the students by examining these data in class.

INTRODUCTION

The past decade has seen many people calling for increased emphasis on general problem-solving skills and the encouragement of flexible and creative thinking as an important element in the education of professionally-oriented students in fields such as management and engineering. This has been a growing emphasis of the AACSB [I], the accrediting body for collegiate business education. In the field of engineering, this concern hind steps to address it have been clearly set out in the book by Adams [21 developed from his work in the Stanford University School of Engineering. In essence, the argument is that skills taught in courses on particular function aspects of a profession usually jail to give a student the bigger picture of human problem-solving .activity and often encourage them to look at new challenges and opportunities only from the angle of the assumptions involved in tie particular analytic procedures they hive mastered.

The course titled "Creativity and Cognition" is taught by faculty of the Applied Psychology Area within Clarkson's School of Management. Typically, about 407. of its enrollment are management students and most of the remainder are in engineering. During the four years since it was first offered, the texts and materials have gone through a number of versions but the objectives hue remained the same: (1) to hive students learn about psychological theory and about research results on human problem solving with a particular emphasis on the topic of creativity and (2) to have students engage in 3 variety of in-class and homework exercises designed to increase their own flexibility of thinking, to increase their ability to conceptualize problems in a variety of ways, and to add to their understanding of their own general problem solving techniques, including strengths and areas for improvement. This second objective of the course is clearly experiential in nature. Prior to this year, materials to facilitate this objective ware limited to 3 book of exercises [3J and a number of challenges and puzzles discussed in class that were drawn from the text and

various ad hoc sources.

As tends to happen with courses that get larger enrollments (often 40 to 50), it is difficult to give enough individual attention and feedback to people. This, in turn, makes it difficult to encourage higher levels of motivation in all students; some will become very involved but others will not do so unless they get greater personalized feedback on the experiential part of the course. A third and quite important difficulty, was related to what the cognitive psychologists [e.g. 4, 51 call 'protocol analysis." This is the detailed recording of steps in solution attempts in order to build models of a particular person's internal representation of the problem and of their solution search methods. It was difficult to give interesting in-class demonstrations of this technique used by cognitive psychologists, and there *was* no practical way of using it for individual students so that they could get better insight into their own processes of problem conceptualization and solution search.

In an effort to solve these problems, a series of programs written in BASIC was developed for the Zenith Z-103. Clarkson has adopted this machine for student usage, and [acuity in the School of Management have been very active in applying it in a variety of courses. All freshmen and sophomores by now have been required to own this machine, and there are many available for public use on campus for those upperclassmen who do not own one. In relation to Creativity and Cognition, one desired effect front using this method was that, in comparison to working on a puzzle/problem in class that was presented on the chalkboard, this would be a more engaging medium that students would be motivated to "play with" outside of class. Class time could then be devoted to discussing the exercise and peoples' experience with it. A second purpose of using these programs is that the computer can be programmed so that people enter various steps of their solution attempts as they manipulate the problem elements on the screen of the microcomputer, and these steps can be permanently recorded in the machine to permit the protocol analysis mentioned above. (other information such as solution time can also be recorded, if desired.) Finally, related to the protocol analysis purpose, by allowing each student to review their own detailed sequence of problem solving steps after they are done and by giving them summary information on their problem-solving efficiency, this methodology permits a kind of feedback that was not previously possible.

In what follows, the four programs developed so far are explained. Then the two that nave had course usage to date are described in more detail along with data on students' problem-solving behavior and with the teaching points demonstrated by these data.

THE PROGRAMS

JUGS is a program that presents a series of Lu "water-jug" problems. Each one involves three jugs

that can hold three different known quantities of water, and the student has an unlimited source of water from which to fill them. Water can be transferred between jugs and they can be emptied. The objective is to . manipulate the jugs as efficiently as possible in order to obtain a desired fourth quantity of water that is specified in each problem. These problems (6, pp. 500-501] are designed to allow people to show rigid patterns of problem solving or to show flexibility. The program records a student's problem solving activity and the tine taken on each problem. The first five problems can all be solved with the same pattern of manipulations on each in a minimal sequence of six steps. The next several are such that the habitual pattern now established will work, but there is also a more efficient method taking fewer steps, Students know they are being timed by the computer. After all students have done the task, its purpose is explained in class and they can review their own data. The main purpose is to allow students to see the costs (in terms of time and amount of activity) that are imposed by habitual modes of thinking and to get individual feedback on whether they showed and or flexible problem solving.

HANOI presents the 'Tower of Hanoi problem [5] in which the objective is to move a stack of different-sized disks from one peg to another while using a Third peg in the process. The rules permit moving only one disk at a time (and only taking it from, the top of a stack) and they prohit ever placing a larger task on top of *a* smaller one. The task is very easy with a small number of disks, but the minimum number of moves increases exponentially with the number of disks. The program presents versions of the problem with one to six disks. Larger-disks versions are usually solved by mentally setting up sub-goals. however, the sequence of goals, subgoals and sub-subgoals gets complex when tie number of disks exceeds Lout. Thus, memory limitations often cause people to take many note steps that the mathematically minimal number. This problem involves planning and goal-setting, and it demonstrates the difficulties with relying on memory in complex problem solving.

MATCHES presents those types of problems involving rearrangement of geometrical configurations of match sticks in a minimal number of moves in order to produce some new desired figure. Some of these problems are discussed in one of the texts for the course [5]. The essential point of these problems is that different initial mental representations for the task (focusing, for example, on single lines versus larger figures such as squares) significantly affect the ease of solution.

CRYPTA presents one of the tasks most widely used by cognitive psychologists for collecting and analyzing problem-solving protocols: the "Donald + Gerald Robert cryptarithmetic problem [4] The problem is this: after setting up these words in columns as in grade-school form-at for addition problems, the objective becomes to find a digit/Letter correspondence between each of the 10 single digits U-to-9 and the ten Letters in this problem such that a valid arithmetic problem results. The program records each trial assignment a person makes and updates the display with the current trial assignments. Assignments can be made, deleted, or changed. After being given the initial clue that "d=5," the remaining nine letters still allow nine-factorial (362,8B0) possible assignments. This makes trial-and-error solution virtually impossible, so the problem requires the use of current partial information states to deduce new information states on the way to a solution.

RESULTS FROM THE JUGS PROGRAM

Students received detailed instructions on how to use the program, and they first worked a practice problems (problem "0"). Then they began the actual problem solving. Figure 1 presents the actual screen layout showing the beginning of problem 1. this program records all steps taken by the student and the time in seconds for each problem. After finishing all problems the program permits the student to review (but not change) all their steps on each problem. Regardless of

FIGURE 1

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PROBLEM  1

in what follows, 'X' and 'Y' stand for the JUG letters 'A','B','C' (lower case)

'1XY' means pour X into Y until Y is full or until X is empty
'2X' means fill X
'3X' means empty X
'0X' means X has the desired amount (go to next problem)


JUG SIZES ARE:  A= 21   B= 127   C= 3   DESIRED AMOUNT= 100

CURRENTLY HAVE: A= 0   B= 0   C= 0

next move (use lower case)?
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whether they do this, after the LU problems are finished, the program prints out a L2-digit number and a 15-digit number that together code the number of steps they took on each problem and the time they took on problems 3 through 3. Students were required to hand in these numbers to the instructor who ran a program to uncode this data the results below were based on this information.

Note the following facts tram Table I: Problems 1-5 set up a pattern wherein o steps solves the problem. By problem 5, more than 75% of the people had learned to use this minimal sequence, and their median time was such that they took about 5 seconds/step. On problem b, crucial in the sense of allowing one to break this pattern or to rigidly stick with it, L& people were flexible enough to use the new minimal sequence of steps while 6 more used the new pattern but

made sortie errors (since they only took 4 or 5 steps, they could not have been using the old pattern); 17 took the 6 steps required by the old pattern and only 3 required more than that number of steps. The remaining problems all gave an option of using a new and simpler pattern, and problem 3 forced the use of a new pattern. Thus, by problem 10, nearly 70% ware solving the problem most efficiently. However, the frequency data for problem & show a clear bi-modal distribution with nearly equal proportions showing either flexible problem solving or a rigid pattern. These results were presented in class and discussed with students. They provide a clear example where a flexible approach greatly reduces the amount of required work. Students wne instructed to go back and review their steps on problem 6 to see into which group they fell.

TABLE 1

JUGS PROBLEM CHARACTERISTICS AND DATA ON NUMBER OF STEPS TO SOLUTION

Problem Number	Jug Sizes A	B	C	Target Amount	Minimum Steps	Numbers of People Taking This Many Steps 3	4	5	6	7	8	9+	Median Times
1	21	127	3	100	6	--	--	--	28	7	4	3	
2	14	163	25	99	6	--	--	--	26	6	4	6	
3	13	43	10	5	6	--	--	--	22	8	3	9	54.5
4	9	42	6	21	6	--	--	--	13	9	0	15	53.0
5	20	59	4	31	6	--	--	--	32	2	3	5	38.0++
6	23	49	3	20	3*	16	4	2	17	2	0	1	25.5
7	15	39	3	18	5	--	--	10	13	8	6	5	36.5
3	23	76	3	25	3**	27	1	0	2	4	0	8	22.0
9	18	43	4	22	5	--	--	17	19	0	0	4	
10	14	36	3	6	3	29	5	1	4	1	1	1	

Note: Sample size for these data is 42.

* This is the crucial problem. This and all below (except 3) can be solved with the old pattern of 6 steps. Use of 6 steps indicates RIGID problem solving.

** This problem FORCES the consideration of a new pattern using only 3 steps.

+ This column has the number of people that took 9 or more steps.

++Looking at each person's best time among problems 3 through 5, 35.5 seconds was the median among these fastest times for each person.

TABLE 2

ANALYSIS OF TIME DATA FROM JUGS COMPARING NEW PATTERN VS. OLD ON PROBLEM 6

	NEW Pattern (n = 22)			OLD Pattern (n = 20)			
Number of steps on problem 6	3	4	5	6	7	8	9+
Number of people with that many steps on problem 6	16	4	2	17	2	0	1
Proportion having time>25.5^ on problem 6 ^(Table 1 OLD vs. NEW summary for above row median)	3/16 6/22	1/4	2/2	13/17 15/20	1/2	---	1/1
Median time on problem 6 WITHIN GROUP (grouping by number of steps on problem 6)	13.0 (3 steps) 19.0* (all 22)			35.0* (6 steps) 35.0 (all 20)			
Proportion having time>38.0^ on problem 5 ^(Table 1 Proportion having time>35.5^ on best of 3-5 med- OLD vs. NEW summary for above two rows ians)	3/16 9/16 11/22---13/22	2/4 2/4	1/2 2/2	9/17 7/17 10/20---8/20	0/2 0/2	--- ---	1/1 1/1
Median time on problem 5 WITHIN GROUP (grouping by number of steps on problem 6) Median time of best times among problems 3 through 5 (grouping by number of steps on problem 6)	33.0 (3 steps:n=16) [38.0 (all 22)] 36.0 (3 steps:n=16) [36.5 (all 22)]			44.0 (6 steps:n=17) [39.0 (all 20)] 34.0 (6 steps:n=17) [33.5 (all 20)]			

* The time of 19 seconds for all 22 people using the NEW pattern (even if they took 4 or 5 steps) is very significantly different from the 35-second time of the 17 people using the OLD pattern most efficiently (6 steps) (p<.0005 by a two-tailed Mann-Whitney U test). (This is the most conservative test that could be made among the figures in these two rows.)

One possible objection to arguing that flexibility saves effort and time is the possibility that those taking only 3 steps did so by pondering the problem for 3 Long period of time before taking any action. Also, one would like to know if the flexible problem solvers differed in the amount of time they took on the earlier problems that did not permit flexibility. Table 2 presents the data relevant to these issues. Based on the overall median of 25.5 seconds for problem 5, only 6/22 of the flexible (NEW pattern) problem solvers took longer periods of time on this problem. In fact, the ratio of the median tines within each group (19 vs. 35 seconds) is nearly 2:1 in favor of flexibility (the ratio of median time / number of steps is still about 6 seconds in both groups). Thus, there is no tradeoff between speed and flexibility; flexibility saved both time and number of steps to solution. Looking at the times off the earlier problems (by the criteria of time on problem 5 and of a person's best time on problems 3 through 5), the bottom part of Table 2 shows that the flexible and inflexible problem solvers were virtually identical: flexible problem solvers were neither speedier on problems that did not permit flexibility nor were they slower and more reflective -- they were simply more open to a new pattern on problem 6. These results were also presented in class and discussed.

RESULTS FROM THE HANOI PROGRAM

When this program started, it asked the student to make choice for the number of disks between 1 and 6. Figure 2 presents the screen layout at a point slightly more than halfway through a six-disk version of HANOI. As mentioned above, this problem is used to 11- lustrate issues related to planning, goal-setting and the problems caused by relying on internal memory to remember goals in problem solving;. For example, in a three-disk version of the problem, to get the three disks from peg 1 to peg 3, one might first formulate the goal of getting the largest disk to peg 3. To do so, one must first get the other two off of it and on to peg 2. To do this, one might next formulate the subgoal of getting the middle-sized disk to peg 2. To accomplish this subgoal, one must first temporarily transfer the smallest disk to peg 3, then transfer the middle-sized disk to peg 2, and then move the smallest disk from peg 3 to peg 2. Finally, the initial goal of getting the largest disk to peg 3 can now be accomplished. One is not done yet, however, since the other two disks are now stacked on peg 2. Therefore, the next goal will be to get the middle-sized disk on to peg 3. This is again accomplished by setting up a subgoal. When that is accomplished, the smallest disk can finally be moved to peg 3. Although this sounds complicated to describe verbally, this set of objectives is easily accomplished by most people who solve the three-disk problem in the minimum required number of 7 steps. The difficulties come as more disks are added to the problem. Each disk adds another level of sub-subgoals to the problem and also about doubles the number of steps required to do the problem most efficiently. It is very easy to forget what subgoal one was working on in such a long sequence of steps.

Students were asked to try HANOI for 3, 4, 5 and 6 disks and to hand in data on the number of steps they actually took on each version of the problem (the program kept a record of the number of steps they took and printed this out after they had found a solution). Table 3 presents the data obtained in this way. As problem complexity increases, the number of people
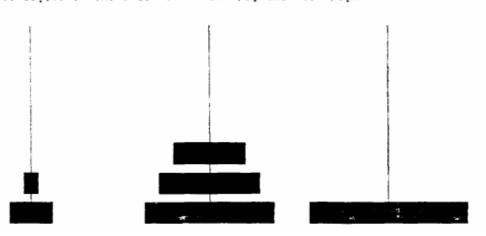
TABLE 3
DATA ON NUMBER OF STEPS FOR HANOI PROBLEM

Disks	Minimum Steps	Number Getting Minimum Steps	Number with No Solution	Median Steps
3	7	38	0	7
4	15	23	0	15
5	31	9	0	37
6	63	4	10	103

Note: Data for this table are based on 41 people.

FIGURE 2

The objective is to move all disks from the left peg (#1) to the right peg (#3),
The intermediate peg (#2) can be used in the process.
Only one disk can be moved at a time.
NEVER place a LARGER disk on a peg with any SMALLER disk already on that peg.

enter two digits in the order of 'from' peg and 'to' peg?

doing the problem most efficiently drops rapidly, the proportion of people unable to do the problem jumps from zero to nearly 25% at 6 disks (one person who finally did solve the six-disk version took 516 steps!), and the median number of steps appears to grow exponentially. These data were also shared with the class as a basis for discussion, and people in the top and bottom thirds of the distribution of efficiency were asked to discuss their strategies for handling the problems. Finally, general points were made about explicitly writing down and keeping track of subgoals in order to manage complex problems.

SUMMARY OF STUDENT REACTIONS

Student interest in working with these programs appears to be high, and problems for those few people unfamiliar with the computer were dealt with quickly. Several students have come to the instructor with questions on additional related topics, with suggestions on how to modify the programs, or with an interest in doing more of this sort of work, It is the instructor's distinct impression that people's understanding of issues in human problem solving is much greater through this experiential presentation of the issues than had been the case in the past with lectures on the issues.

An event as of this writing that best indicates the success of this work, is the enthusiasm with which students have undertaken independent work in groups with the JUGS program. Each group has hypothesized one variable they feel may influence problem solving flexibility vs. rigidity as measured by this JUGS program (for example, one group La studying seniors vs. freshmen, another is Looking at the effects of alcohol, a third is examining time pressure, another is examining the effects of having someone looking over your shoulder, etc.). They currently are gathering data from other students to test their hypotheses and will present their ideas and results in class. This level of participation would have been hard to come by previously.

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