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A Comparison of Two Methods for Completing Sudoku Puzzles

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This study compared two methods for completing Sudoku puzzles. More specifically, students in mathematics classes in Grades 4 and 5 completed Sudoku puzzles using either paper or a specially designed electronic spreadsheet which disallowed the entry of duplicate numbers. Performance was measured by the number of entries in the puzzle and the percentage of correct entries. Results showed that the Grade 5 participants did not differ on either performance measure. On the other hand, the participants in Grade 4 using paper placed significantly more numbers, but the participants using the spreadsheet placed the numbers much more accurately. These mixed results encourage teachers to continually reflect on the utility of instructional technologies in light of learner characteristics and subject matter.

Keywords

mathematical problem solving; instructional technology; Information and Communication Technology; Sudoku puzzles

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Key words: Sudoku, mathematics education, problem solving

1. Introduction

Many people from all parts of the world promote the integration of Information and Communication Technology (ICT) into schools and other societal institutions (United Nations, 2003; United Nations, 2005). The massive effort to promote the use of ICTs in education has resulted in the proliferation of numerous books and articles that promote the integration of technology in education (e.g., Grabe & Grabe 2007; Roblyer 2006; Shelley, Cashman, Gunter, & Gunter 2004). Commensurate with the movement to integrate ICTs in education, school districts, universities, and corporate training entities spend several million dollars annually purchasing, supporting, and maintaining computer systems for instructional purposes. Yet many people are skeptical about the value of ICTs. Critics point to the many failures of technology integration projects in education (Bauerlein, 2008). Further, many articles making claims of the effectiveness of ICTs provide no statistical evidence to support the claims (Johnson & Maddux, 2007). Moreover, the complexity of the problem is rarely broached due to the exceedingly large number of uses of computers in schools.

This study seeks to alleviate those criticisms by focusing on one particular use of technology in a problem solving context and by providing statistical evidence, which may or may not favor a particular method. To gain insight into the use of ICTs in education, the researchers designed a study in which one group of participants completed Sudoku puzzles on paper whereas the other group completed the same puzzles using an electronic spreadsheet which disallowed the entry of duplicate numbers. If it seems likely that disallowing the entry of duplicate numbers would be an obvious advantage, perhaps such a system only lead the participants to believe that as long as the computer accepted the number input, the number entered was correct. To determine the actual effects of the technological approach, this study compared the two groups by number of entries placed and by percentage of correct placements. Specifically, this study pursued these two research questions: (1) Is there a statistically significant difference in the number of entries placed by the participants using the electronic spreadsheet compared to the participants using paper; and (2) Is there a statistically significant difference in the percentage of correct placements made by the participants using the electronic spreadsheet compared to the participants using paper?

Sudoku Puzzles

Typical Sudoku puzzles appear in a 9-row by 9-column (9 × 9) matrix and can be found in newspapers and puzzle books. Though less common, it is also possible to create 4 × 4 and 16 × 16 Sudoku puzzles. Theoretically, the number of rows and columns is n-squared, where n > 1. When n = 1, the puzzle matrix has 1 square and can be solved trivially by placing any symbol in the lone square. When n = 2, the Sudoku puzzle has 4 rows and 4 columns. Figure 1 displays a 4 × 4 puzzle and its solution. In the solution of the puzzle, notice that each row, column, and each of the four internal 2 × 2 squares contains exactly one instance of each number 1, 2, 3, and 4.

4		3	
	2		4
		2	
2			

(a)

4	1	3	2
3	2	1	4
1	4	2	3
2	3	4	1

(b)

Figure 1. Sample 4 × 4 Sudoku puzzle and solution

Figure 2 contains a 9 × 9 puzzle and its solution. Notice that each of the nine rows, columns, and 3 × 3 internal squares contains one instance of each number 1 through 9.

			3		9	8		
	6		1		4	3	5	2
	3		8	2	5	9		
9			7		1			
4			9	3	6			
	1	5	2	4	8	6	7	
6			5			7	4	
	4	3	6		7	1		
	8	7			3		9	6

(a)

7	5	2	3	6	9	8	1	4
8	6	9	1	7	4	3	5	2
1	3	4	8	2	5	9	6	7
9	2	6	7	5	1	4	3	8
4	7	8	9	3	6	5	2	1
3	1	5	2	4	8	6	7	9
6	9	1	5	8	2	7	4	3
2	4	3	6	9	7	1	8	5
5	8	7	4	1	3	2	9	6

(b)

Figure 2. Sample 9 × 9 Sudoku puzzle and solution

The goal of a Sudoku puzzle is to proceed from the start state to the solution. While it is possible to mistakenly create a Sudoku puzzle with more than one solution (e.g., the puzzle in Figure 3 has two solutions), every logically solved Sudoku puzzle (Lewis, 2007) has a unique solution.

1	4	2	3

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2	3		
3	2		
4	1	3	2

Figure 3. Sample Sudoku puzzle with two solutions

It is also possible to create puzzles where the number of rows and columns is equal, but not a perfect square (e.g., see the 6 × 6 puzzle in Welsh, 2007). Since the participants in this study were 10 and 11 years of age, puzzles of size 4 × 4 and 9 × 9 were used.

LITERATURE REVIEW

For the past three decades educators have been promoting the use of ICT in education. Since this study considers the use of ICT in a problem solving context both problem solving and ICT use in education are considered here.

Sudoku Problem Solving

Sudoku problem solving has become increasingly popular since the middle of 2005. Some regard the fascination with Sudoku puzzles as a craze or epidemic, which is how one British mathematician describes the current state of the movement (Wilson, 2006). The popularity of the puzzle aside, educators have reported how knowledge of Sudoku problem solving has afforded insights into problems in other domains, such as failure analysis (Burgess, 2006) and three dimensional problem solving (Macintyre, 2006). Mathematical analyses of Sudoku puzzles have lead to the number of unique puzzles, which is 5,472,730,538 (see Wilson, 2006). A puzzle is unique if it cannot be generated from another puzzle by either a geometric or numerical transformation. For example, switching the first and second columns of any Sudoku puzzle (see Figure 2b, for instance) would not result in a unique puzzle. Also, switching the 1's and 2's, for instance, would yield a numerically transformed puzzle, not a unique puzzle. Mathematical analyses have also revealed the computational complexity to be NP-complete (Lobo, 2007) and to a conjecture that 17 is the minimum number of clues (or initially filled in cells) in a logically solvable puzzle (Wilson, 2006). Mathematicians/computer scientists have also provided diverse analyses of Sudoku problem solving strategies. Eppstein (2005) considers paths and cycles in graphs. Lobo (2007) discusses transformation of Sudoku puzzles to a Satisfiability problem. Simonis (2005) describes Sudoku puzzle solving using constraint problem analyses.

Given that Sudoku puzzles have become popular recently, little time has been available to design and implement disciplined inquiries pertaining to Sudoku problem solving. In the one study we found, Baek, Kim, Yun, and Cheong (2008) considered whether numbers or other symbols affected the logical thinking of participants in Grades 3 and 6 as they solved Sudoku puzzles. Those researchers found differences, but they do not inform this study directly because numbers were used exclusively in the puzzles in this study. One of the unique contributions of this study is the provision of statistical evidence which offers a direct comparison of performance by participants using a specially designed spreadsheet and participants solving the puzzles on paper. This study is also unique in its attention to the performance of students in fourth and fifth grades.

Information and Communication Technology in Education

Since the introduction of microcomputers into classrooms of wealthy nations in the early 1980s, educators have been considering how to include computers in schools. Over the past three decades this conversation has come to include communication technologies in addition to computers, which are referred to more generally as information technologies. As evident in the Summits on Information and Communication Technology (United Nations, 2003; United Nations, 2005), people all over the world seek to leverage ICT for instructional and other purposes. Instructional advantages of using ICT are assumed in many cases and touted without statistical evidence (Johnson & Maddux, 2007). In studies reporting learning gains in which the participants used ICT, any instructional benefit is often attributed to the technology. For example, Knezek and Christensen (2007, p. 25) wrote: “Researchers have known for decades that technology can help improve reading.” Yet one of the more famous results in the field of instructional technology is that instructional method, not delivery medium, accounts for learning gains (Clark, 1983). Nevertheless, even the most ardent proponents of the view that the instructional delivery medium makes no difference in learning effectiveness will readily grant that efficiency gains may well be experienced using certain delivery media (Clark, 2004). Indeed, efficiency gains are often real.

The tremendous increase in the number of distance learners owes much to the ubiquity of computers connected to the Internet. While Internet access remains a challenge in developing countries, especially in rural areas, the number of schools with Internet access continues to increase (Kinuthia, 2009). This study accepts that learners will acquire skills necessary to solve Sudoku puzzles whether using paper or the specially designed electronic spreadsheet. The question here is whether the spreadsheet feature which prevents the entry of duplicate numbers is beneficial or detrimental. Does the spreadsheet actually lead to better performance or does it lead participants toward a false sense of accomplishment that subsequently requires them to spend time changing previously placed numbers after discovering an error?

METHODOLOGY

Participants and Procedures

The 129 participants in this study were students in Grades 4 and 5 at the same public elementary school in the Southeast region of the United States. All of the students in this study received permission to participate from their parents and all of the students participated voluntarily. The study was conducted during mathematics classes in which the students were enrolled. By random assignment, the paper-based or computer-based treatment was assigned to the in-tact classes of students. Students assigned to the paper-based treatment were handed Sudoku puzzles printed on paper, which the students completed at their desks in their math classes. After the students finished each puzzle, the researchers collected the completed puzzles directly from the students.

Students assigned to the computer treatment completed the work in a media center, which contained 25 computer desks and computers. Once the students had arrived in the media center, they logged into a computer and the researchers distributed a diskette to each student. Each student inserted the diskette into the disk drive and opened the spreadsheet file, which displayed the first 4 × 4 puzzle. Each tab in the spreadsheet file contained one Sudoku puzzle. After completing a puzzle, the student saved the spreadsheet file and then clicked on the next tab. At the end of the session, the students saved the spreadsheet file one final time and the researchers collected all of the diskettes. Importantly, the key difference between the paper and computer treatments is that the Excel spreadsheet would not let a participant enter a duplicate number in a row, column, or internal square. The actual Sudoku puzzles used in this study appear in the spreadsheet included with this article. The appendix describes the cell validation programming, which ensures that users never enter a duplicate value in a row, column, or internal square. The cell validation formula does not ensure that the value entered is the correct number for that cell; the validation formula ensures only that the number entered does not duplicate a number already in the same row, column, or internal square.

To teach the participants how to solve Sudoku puzzles, one researcher presented the unsolved 4 × 4 Sudoku puzzle in Figure 1 and told the students what was necessary to solve the puzzle (i.e., each of the digits 1, 2, 3, and 4 must be placed exactly once in each of the four rows, columns, and 2 × 2 internal squares). The researcher then demonstrated how to solve the puzzle. After making the first few placements and stating the rationale for placing the particular number in the particular cell, the researcher called upon a student to state what number had to be placed in a particular cell in the puzzle. This approach was used for a second 4 × 4 puzzle and then the students worked to complete another 4 × 4 puzzle and then a 9 × 9 puzzle on their own. The students in the in-tact classes had one 55-minute period in which to complete the work. Did the participants using the computer correctly enter fewer, essentially the same, or more numbers than the participants who completed the puzzles on paper?

RESULTS

In this study, performance was measured by number of entries placed in the puzzles and percentage of entries placed correctly. Since the participants completed the 4 × 4 puzzles correctly, the results in this section pertain to performance on the 9 × 9 puzzle. In the analyses that follow the t-test is used because the purpose in each of the following analyses is to determine whether the means of two groups are statistically different. Also, the t-test is an inferential statistic, which is useful for drawing conclusions that extend beyond the actual data collected. Initial analyses in this study revealed significant differences among the participants in Grades 4 and 5 on both performance measures. For entries placed by participants in Grade 4 ($M = 22.76$, $SD = 13.63$) and for participants in Grade 5 ($M = 29.22$, $SD = 10.98$); $t(127) = -2.96$, $p < .005$. For percentage of correct placements by participants in Grade 4 ($M = 57.18$, $SD = 27.08$) and for participants in Grade 5 ($M = 74.18$, $SD = 21.88$); $t(121) = -3.83$, $p < .001$. As a result of these initial analyses, the results for the two grades were considered separately.

In the case of Grade 5, for entries placed by participants using paper ($M = 30.95$, $SD = 11.37$) and for participants using the spreadsheet ($M = 28.29$, $SD = 10.79$); $t(61) = .916$, $p > .3$ (not significant). For percentage of correct placements by Grade 5 participants using paper ($M = 74.61$, $SD = 18.70$) and by participants using the spreadsheet ($M = 73.95$, $SD = 23.67$); $t(60) = .11$, $p > .9$ (not significant). These results indicate that for the participants in Grade 5, use of paper or the spreadsheet made no difference.

With respect to Grade 4, for entries placed by participants using paper ($M = 26.23$, $SD = 12.72$) and for participants using the spreadsheet ($M = 14.16$, $SD = 12.17$); $t(64) = 3.54$, $p = .001$. For percentage of correct placements by Grade 4 participants using paper ($M = 52.81$, $SD = 27.44$) and by participants using the spreadsheet ($M = 70.59$, $SD = 21.62$); $t(59) = -2.29$, $p = .026$. In this case the significant difference in number of entries placed can be explained by the extensive setup time in the media center by the participants using the spreadsheet. With approximately 10 minutes less than the participants using paper, fewer entries should be expected by the participants using the spreadsheet. The difference in the percentage of entries placed correctly in favor of the participants using the spreadsheet is noteworthy and receives addition attention in the next section.

As an aside, results of t-tests also revealed no statistically significant differences between female and male participants. This is true for both grades and for both the paper and spreadsheet methods.

LIMITATIONS/CONCLUSIONS

We must use caution when seeking to generalize these results to larger populations of students. First, this study concerns only participants in Grades 4 and 5. Second, the results for Grades 4 and 5 are mixed. Readers may be surprised by the lack of differences among the Grade 5 students. Quite simply, the participants in Grade 5 did not benefit from the spreadsheet, but nor were they hampered by it. Additional studies that allowed participants a longer time to practice may be enlightening. The participants in Grade 4 using the spreadsheet did place a greater percentage of numbers correctly than the participants using paper. This does indicate that the spreadsheet helped the participants in Grade 4. Why might that be so and why was the Grade 5 result not consistent with this? Perhaps students in Grade 4 are challenged more by Sudoku problem solving than Grade 5 students. The statistically significant difference in the mean scores of the Grade 4 and Grade 5 participants does suggest that Sudoku problem solving is more challenging for Grade 4 students compared to Grade 5 students. In this light and given that the Grade 4 students who used the spreadsheet placed more entries correctly than the Grade 4 students who completed the puzzles on paper, this study suggests that the Grade 4 students who used the spreadsheet were able to concentrate on finding correct placements for numbers rather than expending any mental effort on avoiding duplicate entries.

This study revealed that a specially designed spreadsheet helped students in Grade 4 correctly place a greater percentage of values into a Sudoku puzzle compared to Grade 4 students who completed the same puzzle on paper. No such difference was found in Grade 5. This disparity in performance by grade level serves as a reminder of the need to collect and to analyze data in order to assess whether, or to what extent, an information and communication technology benefits students.

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Appendix

The validation formula from Cell B7 of Puzzle 4 appears below.

> =AND(INT(CELL("contents"))=CELL("contents"),CELL("contents")>0,CELL("contents")<10,COUNTIF(B7:J7,CELL("contents"))=1,COUNTIF(B7:B15,CELL("contents"))=1,COUNTIF(B7:D9,CELL("contents"))=1)

In total, the validation formula tests six conditions. The AND function ensures that the spreadsheet will accept the value entered only when all six conditions are true. The first condition is INT(CELL("contents"))=CELL("contents"). The INT function truncates any decimal value entered by the user. The CELL function in the validation formula contains the parameter "contents," which returns the value entered by the user. Comparing the truncated result to the value entered ensures that only integers are valid. The next condition, CELL("contents")>0, ensures that the value entered is greater than zero and the following condition, CELL("contents")<10, ensures that the value entered is less than 10. Collectively, the first three conditions ensure that the user enters an integer between 1 and 9, inclusive. The remaining three conditions rely on the COUNTIF function, which returns the number of times a Boolean expression is true in a particular range of cells. The first parameter in the COUNTIF function is the range of cells and the second parameter is the expression. Hence, COUNTIF(B7:J7,CELL("contents")) is true every time the integer entered by the user appears in the nine cells from Cell B7 to Cell J7. Comparing that result to 1 ensures that the integer entered by the user must be unique among the cells from B7 to J7, which in this particular spreadsheet is the top row of the Sudoku puzzle. The condition, COUNTIF(B7:B15,CELL("contents"))=1, ensures that the value entered by the user will be unique compared to all values in the B7 to B15 range, which in this spreadsheet is the first column of the Sudoku puzzle. Lastly, the condition, COUNTIF(B7:D9,CELL("contents"))=1, ensures that the value entered by the user will be unique compared to all values in the B7 to D9 range, which in this spreadsheet is the upper-left internal square of the Sudoku puzzle.