Journal of Mathematics Education at Teachers College

Spring – Summer 2011

A Century of Leadership in Mathematics and its Teaching

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The *Journal of Mathematics Education at Teachers College* is a publication of the Program in Mathematics and Education at Teachers College Columbia University in the City of New York.

This issue honors Clifford B Upton who was a senior member of the Teachers College faculty from 1907 until his retirement in 1942. Professor Upton was among the Nation's most prolific mathematics authors. He served on the Board of Directors of the American Book Company enabling him to endow the Clifford Brewster Chair of Mathematics Education. The first professor to hold the Upton Chair was Dr. Myron Rosskopf.

Bruce R. Vogeli has completed 47 years as a member of the faculty of the Program in Mathematics, forty-five as a Full Professor. He assumed the Clifford Brewster Chair in 1975 upon the death of Myron Rosskopf. Like Professor Upton, Dr. Vogeli is a prolific author who has written, co-authored or edited more than two hundred texts and reference books, many of which have been translated into other languages.

This issue's cover and those of future issues will honor past and current contributors to the Teachers College Program in Mathematics. Photographs are drawn from the Teachers College archives and personal collections.

Aims and Scope

The *JMETC* is a re-creation of an earlier publication by the Teachers College Columbia University Program in Mathematics. As a peer-reviewed, semi-annual journal, it is intended to provide dissemination opportunities for writers of practice-based or research contributions to the general field of mathematics education. Each issue of the *JMETC* will focus upon an educational theme. The theme planned for the 2011 Fall-Winter issue is: *Technology*.

JMETC readers are educators from pre K-12 through college and university levels, and from many different disciplines and job positions—teachers, principals, superintendents, professors of education, and other leaders in education. Articles to appear in the *JMETC* include research reports, commentaries on practice, historical analyses and responses to issues and recommendations of professional interest.

Manuscript Submission

JMETC seeks conversational manuscripts (2,500-3,000 words in length) that are insightful and helpful to mathematics educators. Articles should contain fresh information, possibly research-based, that gives practical guidance readers can use to improve practice. Examples from classroom experience are encouraged. Articles must not have been accepted for publication elsewhere. To keep the submission and review process as efficient as possible, all manuscripts may be submitted electronically at www.tc.edu/jmetc.

Abstract and keywords. All manuscripts must include an abstract with keywords. Abstracts describing the essence of the manuscript should not exceed 150 words. Authors should select keywords from the menu on the manuscript submission system so that readers can search for the article after it is published. All inquiries and materials should be submitted to Ms. Krystle Hecker at P.O. Box 210, Teachers College Columbia University, 525 W. 120th St., New York, NY 10027 or at JMETC@tc.columbia.edu

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Call for Papers

The "theme" of the fall issue of the *Journal of Mathematics Education at Teachers College* will be *Technology*. This "call for papers" is an invitation to mathematics education professionals, especially Teachers College students, alumni and friends, to submit articles of approximately 2500-3000 words describing research, experiments, projects, innovations, or practices related to technology in mathematics education. Articles should be submitted to Ms. Krystle Hecker at JMETC@tc.columbia.edu by September 1, 2011. The fall issue's guest editor, Ms. Diane Murray, will send contributed articles to editorial panels for "blind review." Reviews will be completed by October 1, 2011, and final drafts of selected papers are to be submitted by November 1, 2011. Publication is expected in late November, 2011.

Call for Volunteers

This *Call for Volunteers* is an invitation to mathematics educators with experience in reading/writing professional papers to join the editorial/review panels for the fall 2011 and subsequent issues of *JMETC*. Reviewers are expected to complete assigned reviews no later than 3 weeks from receipt of the manuscripts in order to expedite the publication process. Reviewers are responsible for editorial suggestions, fact and citations review, and identification of similar works that may be helpful to contributors whose submissions seem appropriate for publication. Neither authors' nor reviewers' names and affiliations will be shared; however, editors'/reviewers' comments may be sent to contributors of manuscripts to guide further submissions without identifying the editor/reviewer.

If you wish to be considered for review assignments, please request a *Reviewer Information Form*. Return the completed form to Ms. Krystle Hecker at hecker@tc.edu or Teachers College Columbia University, 525 W 120th St., Box 210, New York, NY 10027.

Looking Ahead

Anticipated themes for future issues are:

Fall 2011	Technology
Spring 2012	Evaluation
Fall 2012	Equity
Spring 2013	Leadership
Fall 2013	Modeling
Spring 2014	Teaching Aids

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Spring–Summer 2011, Volume 2

Using Simplified Sudoku to Promote and Improve Pattern Discovery Skills Among School Children

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As part of promoting and improving pattern discovery skills among school children, a Sudoku puzzle can be used as example of a problem solving task. A simplified version of the puzzle will be used first to explain the aim and reinforce the rules of solving the puzzle. Three strategies—*Strategy of 'Obvious Missing Number'*, *Strategy of 'Elimination'*, and *Strategy of 'Either This or That'*—will then be introduced and applied in solving a simplified Sudoku puzzle that is appropriate for children in grades 4 to 6.

Keywords: Sudoku, problem solving, puzzle, recreational mathematics.

Introduction

The Common Core State Standard Initiative (National Governors Association & Council of Chief State School Office, 2010) states that in mathematics, students are expected to *learn not only procedural but also conceptual ideas*, *practice applying mathematical ways of thinking to real world issues and challenges*, and *develop a depth understanding and ability in applying mathematics*. One approach that can be adopted to achieve these goals is teaching mathematics through problem solving. Stanic and Kilpatrick (1989) state that problem solving can be used as a justification for teaching and learning mathematics, as a source of motivation for students learning, as a vehicle of teaching new concepts and skills, as a form of practice to reinforce skills and concepts, and as an art of mathematical discovery, among others.

One of the skills that children need to have in approaching problem solving tasks in mathematics is pattern discovery skill. This skill cannot be taught; however it can be developed among children. Many tasks, including games and puzzles, can be used to develop and improve such skills. A simple puzzle such as Rubik's cube can be used to teach problem solving (Rohrig, 2010); studies have shown the benefits of using games in learning (Barab, Gresalfi, & Arici, 2009; Shaffer, Squire, & Gee, 2005). Evered (2001) stated that using puzzles in class can increase the excitement of students and promote and motivate their learning.

One creative and inexpensive game that can be used by teachers to promote the skills in problem solving is the simple, modern puzzle called Sudoku. Sudoku, like any other puzzle, can be engaging, addictive, and provide a sense of achievement when fully completed. One of the main benefits of using Sudoku puzzles in learning is that it strengthens the mathematical skills that are required to solve such puzzles, which include trial and error, guess and check, logical reasoning, narrowing down of choices, looking for patterns, the process of elimination, and others. Sudoku has also been mentioned as a possible way to slow down the progression of Alzheimer's in patients (Critser, 2006). Due to the flexibility and its rich mathematical application, Sudoku has been used not only as a teaching medium in different levels and areas of mathematics (*Enumerating Small Sudoku Puzzle in a First Abstract Algebra Course*, Lorch & Lorch, 2008; *Using Sudoku to Introduce Proof Techniques*, Snyder, 2010), but also in other subjects such as Chemistry (*Sudoku Puzzles as Chemistry Learning Tools*, Crute & Myers, 2007) and Computer Science (*A Generic Framework for Local Search: Application to the Sudoku Problem*, Lambert, Monfroy & Saubion, 2006).

In this article, simplifying the concept of the game will demonstrate how teachers can guide children to apply three strategies of discovering patterns found in Sudoku. Introduction of the concept of these patterns will be demonstrated using the simpler 3 X 3 grid, 9 X 1 grid and 1 X 9 grid, which teachers can use as reinforcement and practice for children. An easy, ability-appropriate version of the 9 X 9 grid puzzle will then be used to demonstrate the combination of these patterns in solving the puzzle.

What is Sudoku?

Despite the existence of older versions of the puzzle with different names, the modern Sudoku (meaning 'Single Number') puzzle—which is believed to have rooted from the number puzzle 'Latin Square' invented by Leonard Euler in the 18th century—was first introduced and made popular in Japan in 1984 (Nishiyama, 2010). The simple, yet at times, challenging nature of the puzzle has made it popular throughout the world in the last decade.

The puzzle consists of a 9 x 9 grid (Figure 1), where starting numbers are included in the puzzle—the amount of given numbers is inversely proportional to the level of difficulty. The goal of a Sudoku puzzle is to fill in the digits 1 to 9 so that no digits are repeated in any column, row, or each of the nine 3 x 3 sub-grids, also called blocks, that divide the puzzle. Variations of the puzzle, such as those with irregular 3 x 3 sub-grids, are also available for more advanced players.

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

Figure 1. Modern Sudoku Puzzle

Throughout this article, columns will be referred to as one to nine from left to right, while rows will be one to nine from top to bottom, and blocks will be numbered one to nine from left to right as we move downwards (Figures 2.1 and 2.2).

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

Figure 2.1. Columns and Rows in Sudoku Puzzle

	1			2			3	
	4			5			6	
	7			8			9	

Figure 2.2. Blocks in Sudoku Puzzle

Introducing Three Strategies for Solving Sudoku to Children

The Sudoku puzzle itself can be viewed as a problem solving task. Since the students are unfamiliar with the puzzle and might be overwhelmed when trying to solve the puzzle for the first time, the task of solving the puzzle is simplified by reducing the size. The game of Sudoku should be introduced to children with the 3 X 3 grid, 1 x 9 grid, and 9 X 1 grid puzzles to facilitate their understanding of the rules and concepts, similar to Polya's (1973) suggestion of *Starting with a Simpler Problem* as one heuristic when solving a 'difficult' problem.

There are many approaches that have been suggested in solving Sudoku puzzles: Scanning single and multiple rows and column, Listing possibilities, Number pairs (Naylor, 2006); The Row Rule, Column Rule and Box Rule (Snyder, 2010); Crosshatching, Slicing and Dicing, Penciling in, Single candidate squares, Number claiming, Pairs, Triplet (Stephens, 2005); Lone number, Twins, Triplets, Elimination, Ariadne's Thread (Mepham, 2005). However, only three basic and simple strategies of discovering patterns will be introduced in this article, mainly to ensure appropriateness for the target age of students in grades 4 to 6. The three strategies will be referred to as: *Strategy of 'Obvious Missing Number', Strategy of 'Elimination'*, and *Strategy of 'Either This or That'*.

To familiarize students with the puzzle, the activity begins by handing out empty sets of 3 X 3, 1 X 9 and 9 X 1 grid puzzles and allowing the children to arrange the digits 1 to 9 however they would like (Figures 3.1., 3.2. and 3.3.).

Figure 3.1. A 3 X 3 Grid

Figure 3.2. A 9 X 1 Grid

Figure 3.3. A 1 X 9 Grid

Using a few samples completed by the children for group discussion and comparison, teachers can introduce the definition of block, column, and row, and begin reinforcing the goal that no digit should be repeated within any block, column or row (Figures 4.1., 4.2. and 4.3.)

4	9	7
1	8	2
6	3	5

Figure 4.1. Possible Sample

1
2
3
4
5
6
7
8
9

Figure 4.2. Possible Sample

3	7	5	8	1	9	4	6	2

Figure 4.3. Possible Sample

Strategy of 'Obvious Missing Number'

During the introductory activities, teachers should begin by giving students grids with one digit missing. These grids will be used to explain the strategy of a *Missing Number*. Since the previous activity highlighted that there should not be repeating digits in any block, column or row, this pattern can easily be recognized and applied by the children, thus being named *Strategy of 'Obvious Missing Number'* (Figure 5).

Strategy of 'Elimination'

In order to introduce the strategy of 'Elimination', the next part of the activity will focus on the entry of just a single digit in a particular column or row—in the example provided (Figure 6) we use the digit 3. Provide a copy of Figure 6 to the students and highlight the *restricting number* found outside the grid. It should be stressed that a *restricting number* represents a number that should not be included within the column or row designated by the *restricting number*, where in this case, the digit 3 should not be placed in column 2. Students should fill in the block with the digits 1 to 9, taking care to avoid use of the restricting number in the designated column.

	3	

Figure 6. A 3 X 3 Grid with restricting number

In the classroom setting, teachers can discuss some of the possible samples completed by students. At this stage, it is important for teachers to explain the reason behind some of the different outcomes. Although column 2 has been eliminated as the possibility of entering the digit 3, six available grids remain for placing the digit 3. Introduction of an eliminating line and highlighting the allowed grids for which the digit 3 can be entered visually clarifies the limitation posed by a restricting number (Figure 7).

Following this, teachers should introduce examples with more restricting numbers, to highlight the use of multiple eliminating lines to find the possible (or only) options for placing the digit (Figures 8 and 9).

Provide and reinforce this strategy by giving more examples with multiple restricting numbers in different positions, not only in the 3 x 3 grid, but those of 9 X 1 grid and 1 x 9 grid (Figure 10).

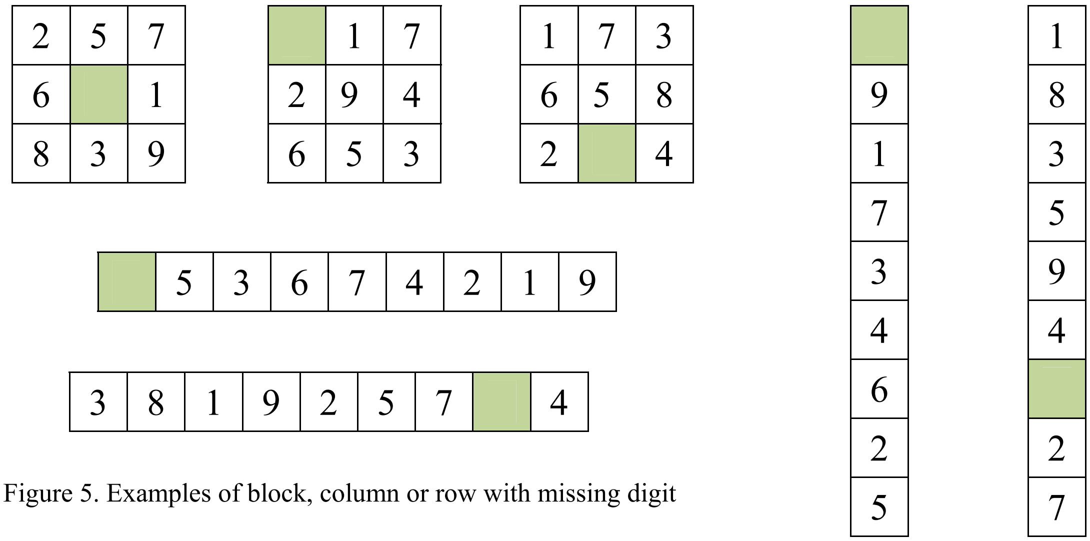

Figure 5. Examples of block, column or row with missing digit

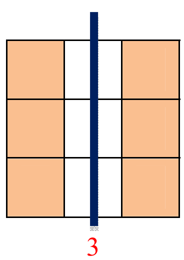

Figure 7. Using an Eliminating line and highlighted grids to explain the possibilities for digit 3 entry

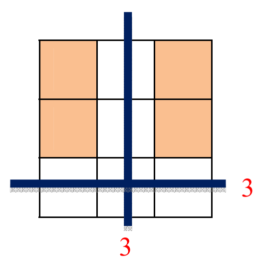

Figure 8. Using multiple Eliminating line and highlighted grids to explain the reduced possibilities for digit 3 entry

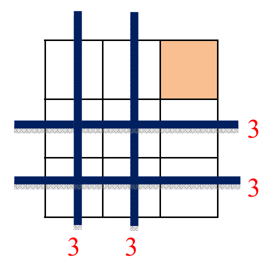

Figure 9. Using more restricting numbers and eliminating lines to explain the only possibility for digit 3 entry

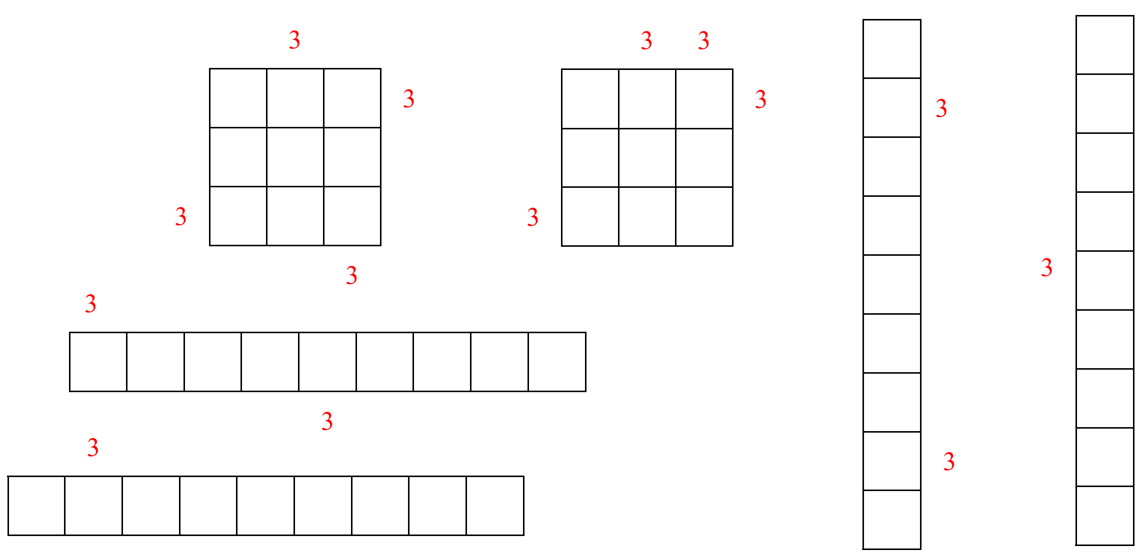

Figure 10. Examples of block, column or row with restricting numbers

Strategy of 'Either This or That'

For the strategy that employs the third pattern in this article, we begin by introducing a block that has two missing digits. In the classroom setting, teachers should solicit which two digits are missing (i.e. numbers 1 and 7 in Figures 11 and 12 below) and ask how they should be placed. At this point, it is beneficial for teachers to incorporate other mathematical learning strategies, such as guess and check, coming up with reasonable possibilities, etc., in order to highlight that each grid can be inserted with 'Either This or That' digit. For this particular example, with input from students through discussion and reasoning, the teacher should demonstrate the two possible outcomes for entering the digits 7 and 1 (Figure 11 and 12).

6	4	8
9	5	2
3	7	1

Figure 11. Digit 7 in left grid, digit 1 in right grid

6	4	8
9	5	2
3	1	7

Figure 12. Digit 1 in left grid, digit 7 in right grid

At this stage, the teacher should reintroduce the concept of a restricting number, by placing it in an appropriate column. The restricting number works in conjunction with the strategy of 'Either This or That' to narrow down the options to only one possible solution. For this example, the digit 7 is used as a restricting number in the second column. Doing so results in the desired outcome, Figure 13, where the digit 7 can be placed only in column three.

	7	
6	4	8
9	5	2
3	1	7

Figure 13. Introduction of restricting digit 7 in the second column forces digit 1 on left grid.

Similar to the previous activities, teachers should allow students to repeat this section with more examples of blocks, columns and rows with two missing digits and restricting numbers (Figure 14).

Additional practice should also be done to reinforce how all three strategies work before applying them simultaneously to complete a 9 x 9 puzzle.

Applying the Three Strategies to Solve an Easy Level Sudoku

Once students are familiar with the three strategies, they can be introduced to a 9 X 9 grid Sudoku puzzle and guided towards applying each individual strategy or combinations of them to solve the puzzle, with a few

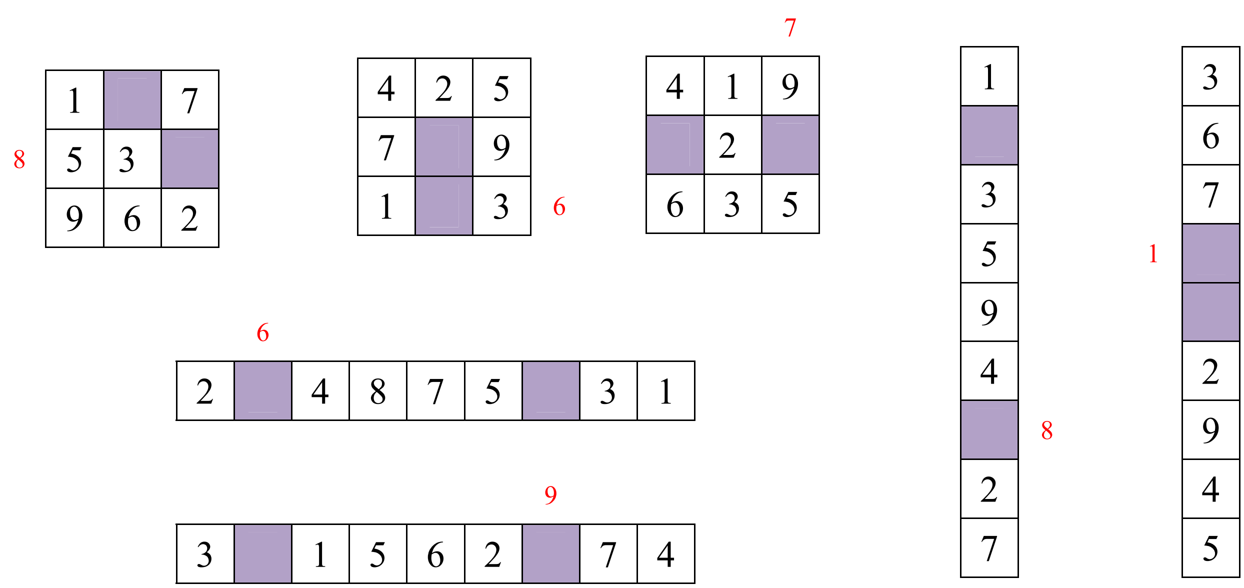

Figure 14. Examples of blocks, columns and rows to reinforce the *strategy of 'Either This or That'*

adaptations along the way. By allowing the students to master the three strategies separately beforehand, students are less overwhelmed in attempting to complete the full Sudoku puzzle, while teachers also gain greater opportunities to involve students in the solving process through discussion, proposal of strategies, reasoning, making choices, etc.

Begin by using the puzzle illustrated in Figure 15. This particular puzzle, initially obtained from the website dailysudoku.com, has been simplified from its original format not only to ensure appropriate level for the target students, but also to enable application of the three strategies introduced in this article for solving the puzzle.

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

Figure 15. Easy level Sudoku

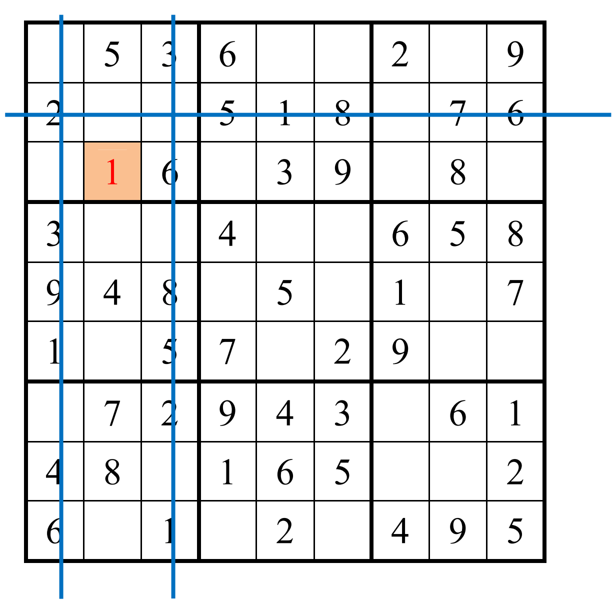

Figure 16.1. Explanation using the concept of eliminating lines and highlighted grid

We shall start this part of the activity by looking for places to enter the digit 1 using the s*trategy of 'Elimination'*. Focusing on the first block, since digit 1 is already found in column one and three, digit 1 can only be placed in either row two or three of the second column of block one. However, digit 1 is also found in row two, thus forcing digit 1 to be placed in the third row of the second column, which can be illustrated clearly by using eliminating lines and highlighted grids (Figure 16.1); alternatively, focusing on block one, teachers could explain this by using a restricting number of 1 in column one, column three and row two (Figure 16.2.).

This elimination process should be repeated for digit 1 entry in blocks 3 and 5, where teachers could adopt other teaching strategies such as group work, discussion and even individual presentation to encourage students' participation that will reinforce understanding of the slightly modified elimination strategy.

At this stage, some students may not grasp the concept immediately, thus the strategy should be reinforced several times with different numbers at the discretion of the teacher until students feel comfortable with the application of the skills. Upon completion of every entry of digit 1 in the puzzle, the same procedure can be applied for digit 2 and digit 3 entries. Teachers should highlight to the students that in each case there should be nine of every digit (Figures 17 and 18 respectively).

This approach of using the *strategy of 'Elimination'* could be continued for the entries of subsequent digits; however, if possible, it would be useful to incorporate the other pattern strategies at this stage. Upon completion of entering every digit 3 for the puzzle by using the *strategy*

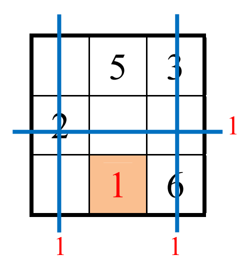

Figure 16.2. Explanation using the concept of restricting numbers

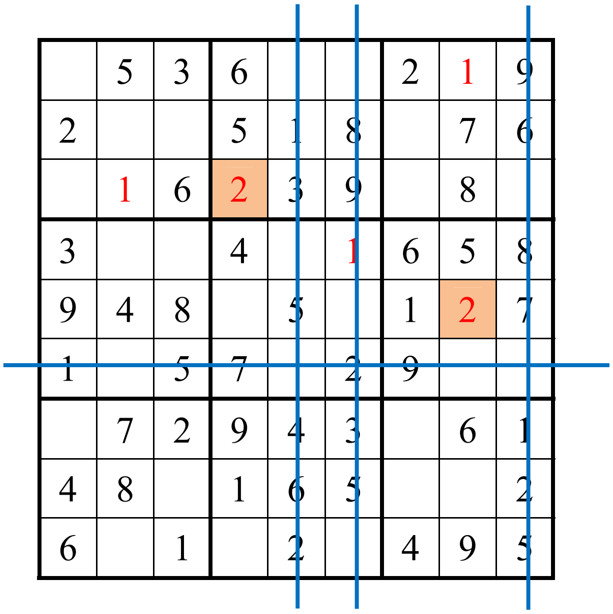

Figure 17. Applying *strategy of 'Elimination'* to complete digit 2 entry

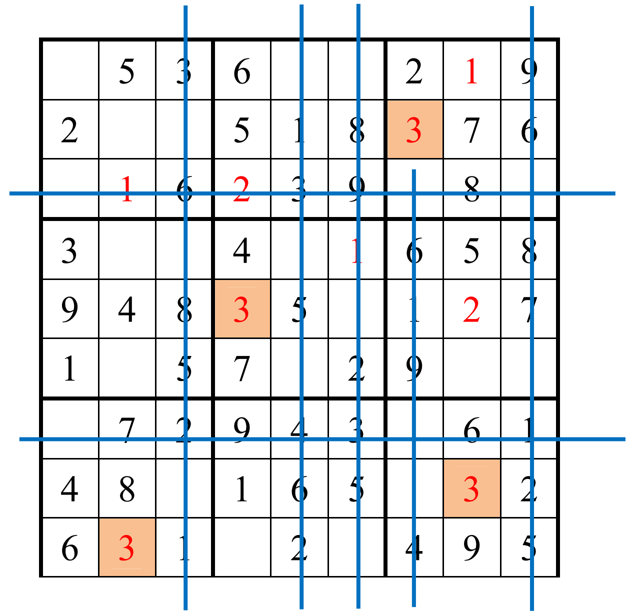

Figure 18. Applying *strategy of 'Elimination'* to complete digit 3 entry

of 'Elimination' (above), the puzzle should look like the one illustrated in Figure 19.1. At this point, students should observe that column four, column eight, and row five have only a single digit missing. Thus, the *strategy of 'Obvious Missing Number'* can be used which will result in Figure 19.2.

This result immediately produces two more cases (row 9 and block 6) that have only a single digit missing, for which students can apply the same strategy (Figure 20).

In the final stage, there are several options that students could use to incorporate and employ the three patterns and strategies discussed in this article. However, for the purpose of this article, the focus will include introducing and applying the *strategy of 'Either This or That'*. For simplicity, we shall start by just focusing on block seven and row six.

In block seven, there is an option of placing the digits 5 or 9 in the two empty grids. However, it can be observed

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

Figure 19.1. Puzzle after digit 3 entry

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

Figure 19.2. Resulting puzzle after entering missing number in column four, column eight and row five

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

Figure 20. Resulting puzzle after entering missing number in column nine and block six

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

Figure 21. Applying the *strategy of 'Either This or That'* to row six and block seven

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

Figure 22. Reinforcing the *strategy of 'Either This or That'* to column one, column three, block three and block nine

that digit 9 is already in column one, leaving only digit 5 that can be entered in column one of block seven. By default, this results in digit 9 being entered in column three. This is confirmed with the presence of digit 5 in column three, simultaneously restricting the entry of digit 5 in that particular column.

Similarly, in row six, digit 6 or 8 could be entered in the empty grids; however, the presence of restricting numbers 6 (in column five) and 8 (in column two) results in digit 6 being placed in column two and digit 8 in column five. Both cases are illustrated in Figure 21. For reinforcement of this strategy, the same procedure should be repeated for column one, column three, block three and block nine (Figure 22).

By this stage of the activity, children should be familiar with the three strategies that have been introduced in this article. It would be advisable for teachers to give students the freedom to choose their own approach in completing the last three empty digits, focusing explicitly on the reasoning behind their choice of approach. The completed puzzle is illustrated in Figure 23.

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

Figure 23. The completed version of Sudoku puzzle introduced as Figure 15

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

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

Figure 24. More easy level Sudoku puzzle

Conclusion

The aim of this article is to give teachers basic guidelines and the confidence to incorporate Sudoku in their mathematics classes in order to expand their teaching approaches and the learning skills of students, or simply just as a recreational activity in which the students will be engaged and interested. As you would expect in any game that is new to an individual, child or adult, there will be some confusion and unfamiliarity with how to approach, strategize, and solve the puzzle. More examples of the simple Sudoku puzzles are included at the end of this article as possible follow-up activities to be used by the teacher as part of the reinforcement and familiarization with identifying patterns and employing strategies for the students (Figure 24). As these three strategies are developed and reinforced, students should be able to discover and adopt further strategies suggested by other authors mentioned in the beginning of this article, allowing them to move on to more advanced levels of Sudoku.

Note: The Sudoku puzzles used in this article were obtained from the easy level classic Sudoku archives found in the website www.dailysudoku.com, but further simplification was done to ensure that the levels were suitable for school children.

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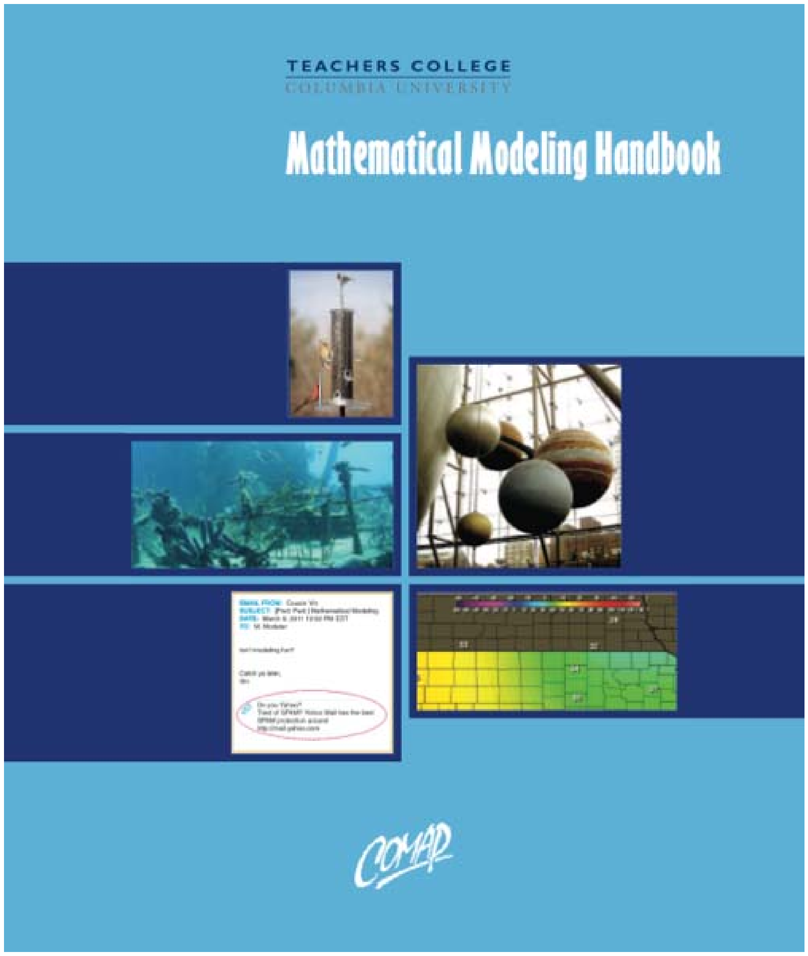

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