The difference in Sudoku puzzle-solving ability between undergraduates and postgraduates

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Abstract: As Sudoku is sweeping around the world, it seems to be increasingly prevalent that Sudoku can contribute to the cultivation of logical thinking ability. In the study, empirical approach was adopted to investigate differences in Sudoku puzzle-solving ability and metacognitive ability of mathematical problem-solving between undergraduates and postgraduates, and to examine the relationship between Sudoku puzzle-solving ability and metacognitive ability of mathematical problem-solving. All participants in the study were students studying in Beijing Normal University. The results indicate: (a) no difference between undergraduates and postgraduates in solving the same level Sudoku puzzles and metacognitive ability of mathematical problem-solving, and (b) metacognitive ability of mathematical problem-solving having no significant effect on Sudoku puzzle-solving ability. However, the number of Sudoku puzzles participants had ever finished had appreciable impact on Sudoku puzzle-solving.

Keywords: Sudoku, undergraduates, postgraduates, metacognitive ability

1. Introduction

Sudoku is a logic-based combinatorial (Lenstra, Kan, & Shmoys, 1985) number-placement puzzle. The objective is to fill a 9×9 grid with digits so that each column, each row, and each of the nine 3×3 sub-grids that compose the grid contain all of the digits from 1 to 9. The puzzle setter provides a partially completed grid, and every puzzle has a unique solution (Wayne, 2006).

Problem-solving is a kind of mental activity of seeking methods to deal with problems when facing new situations and new tasks or realizing a lack of ready-made countermeasure to deal with the contradiction between subjective and objective needs in daily life and social practice. Mathematical problem-solving is one of the most important basic processes in mathematic thinking. Researchers defined mathematical problem-solving from the perspective of cognitive theories that it's a process of a series of perceiving (information processing) which depend on cognitive operator with the guidance of target problem and the information provided by the problem (Jinqiu, 1995).

As to metacognition, different scholars define it differently. Metacognition theory considers human learning a procedure of not only conceiving, memorizing, understanding and processing memory materials but self-perceiving, controlling and modulating cognition process. All in all, metacognition is participants perceiving their cognitive activities (Xueying, 2008). Berardi-coletta et al. (1995) tested college students by a traditional question named tower of Hanoi and got a conclusion that metacognition training is good for solving problems. Ping Yu's (2002) research indicated that metacognition level shows a close correlation with mathematic problem-solving ability for senior high school students. Besides, there are researches which indicate that we can improve students' mathematical problem-solving ability by developing their metacognitive ability (Yan, 2005).

Sudoku puzzles are popular all around the world. According to the media that children can improve their logical thinking ability and develop intelligence by solving Sudoku puzzles, while middle-aged people can bring back their energetic mind and throw away life pressure (Song, 2005). Currently some schools of China organize students to solve Sudoku puzzle at math class regularly, expecting to improve students' math scores. But can Sudoku puzzles really improve students' math scores? In the existing literature there are a lot about strategies and arithmetic in solving Sudoku puzzles such as a 9*9 solving strategy introduced by Davis (2006). Some studied how Sudoku puzzles influence

humans. For example, Baek, et al. (2008) indicated that Sudoku puzzles can help people develop their logical reasoning ability. There are other researchers focusing on other topics with Sudoku puzzles. Such as Chuen-Tsai Sun et al. (2011), they used Sudoku puzzles as the digital scaffolding to study problem-solving behavior with the premise that if a player can solve the Sudoku puzzles from one level to a higher one, his ability is improved in solving Sudoku puzzles.

However, there is more experience than empirical studies about weather Sudoku puzzles can lead to those changes. No information illustrates a specific function of Sudoku puzzles neither facilitation in students' math scores and mathematical problem-solving ability.

This study aims at probing the relationship between metacognitive ability of mathematical problem-solving and Sudoku puzzle-solving ability. By comparing science undergraduates and postgraduates' metacognitive ability of mathematical problem-solving and Sudoku puzzle-solving ability, we expect to reveal the relationship between the two kinds of ability and explore whether Sudoku puzzles has a close correlation with math scores and mathematical problem-solving ability. The follows are hypotheses of the study.

(a) There is significant difference in metacognitive ability of mathematical problem-solving between undergraduates and postgraduates.

(b) There is significant difference in Sudoku puzzle-solving ability between undergraduates and postgraduates.

(c) Metacognitive ability of mathematical problem-solving has appreciable effect on Sudoku puzzle-solving.

(d) Average math scores in senior high school have positive correlation with Sudoku puzzle-solving ability.

2. Methods

2.1 Participants

30 students of Beijing Normal University were selected by convenient sampling, 15 science undergraduates and 15 science postgraduates. 29 participants came from the school of educational technology, 1 from mathematics. As to gender, postgraduate group consists of 5 males and 10 females, and undergraduate group consists of 4 males and 11 females.

2.2 Materials

2.2.1 Metacognitive ability questionnaire

Two parts form the questionnaire, one part for fundamental information including participants' gender, major, the number of done Sudoku puzzles before the study and average score of math in high school, and the other part for testing the participants' metacognitive ability of mathematical problem-solving which is a scale including 37 items.

The 37 items come from a metacognition scale in mathematical problem-solving compiled by Jianlan Tang et al. of Guangxi Normal University in 2005, which is a comprehensive analysis of Panaeula's questionnaire, Skalower and Sbingling's questionnaire, Jianyue Zhang's self-monitoring ability questionnaire in math among middle school students, Ping Yu's self-monitoring ability questionnaire in mathematical problem-solving, and Haiyan Guo's dynamic and static metacognitive questionnaire with a series of unstructured questionnaire verbal reports in problem solving process. This scale is a structured original questionnaire adopting a five Likert scale. In the scale, Metacognitive ability is divided into 3 main factors and 37 items. The main factors are metacognitive knowledge, metacognitive experience, and metacognitive strategy. The sum score of these 37 items a participant get is seemed as metacognitive ability score. The scale's α coefficient of the total internal consistency is 0.901, indicating a good reliability and validity (Jianlan, Ying & Fucheng, 2005).

As mentioned earlier, metacognitive ability has a close correlation with mathematic problem-solving ability (Ping, 2002. Yan, 2005). In the study, we regarded the metacognitive ability score as participants' mathematic problem-solving ability.

2.2.2 Sudoku puzzles

Sudoku is a number-placement puzzle with the rule that each column, each row, and each of the nine 3×3 sub-grids that compose the grid contain all of the digits from 1 to 9 but no repetition is allowed.

We selected 9 basic Sudoku puzzles from Sudoku puzzles (2006) compiled by Wayne Gould in New Zealand. Every puzzle is presented on a half of A4 paper.

The maximum score of each puzzle is 10. The score of each puzzle a participant got is according to the participant finished percentage in total blanks. A participant's Sudoku score is the sum of 9 Sudoku puzzles' scores he got in 1 hour. In the study, we regarded the Sudoku score a participants got as his/her Sudoku puzzle-solving ability.

2.2.3 Interview question

A brief interview question was designed to investigate participants' attitude towards Sudoku puzzles. The question is "Do you want to do Sudoku puzzles in the future?"

2.3 Research process

In order to make the study more reasonable and achievable, a pilot study was conducted in which 2 undergraduates participated, and then we revised some details of the study with their advice. The 15 undergraduates didn't include the 2 undergraduates participated in pilot study. Every participant decided specific time respectively from Dec. 20th, 2013 to Jan. 6th, 2014. It took each participant about 70 minutes. Below was the detailed process.

(a) A researcher explained to the participant the study content, purpose and what they would do.

(b) The participant filled in the metacognitive ability questionnaire. It took about 3 minutes.

(c) A researcher gave the 9 Sudoku puzzles to the participant, explained what was Sudoku and the rule, and remind the participant that he/she could choose a few to do, not all.

(d) The participant got down to Sudoku puzzle-solving for 1 hour with pencils and erasers.

(e) A researcher asked the participant the interview question and recorded the answer.

3. Results

SPSS was used to analyze the data of the study. Significance level was 0.05.

3.1 Differences in metacognitive performance and Sudoku puzzle-solving performance

Independent-Samples T test was used to test the differences in metacognitive performance and Sudoku puzzle-solving performance between undergraduates and postgraduates (Table 1, Table2).

Table 1: Two-tailed t-test results for undergraduates and postgraduates' metacognitive scores.

Dimension	Group	N	Mean	SD	Sig.(two-tailed)
Metacognitive knowledge	Undergraduates	15	27.00	6.36	0.665
	Postgraduates	15	26.13	4.31	
Metacognitive experience	Undergraduates	15	19.40	5.53	0.944
	Postgraduates	15	19.53	4.75	
Metacognitive strategy	Undergraduates	15	60.27	12.31	0.447
	Postgraduates	15	63.40	9.78	
Total score	Undergraduates	15	106.67	21.52	0.729
	Postgraduates	15	109.07	15.64	

As shown in Table 1, the difference of undergraduate and postgraduates' total mean scores is 2.40. The mean scores of undergraduate and postgraduates are very close in metacognitive knowledge

and metacognitive experience dimensions, and score differences in metacognitive strategy dimension is 3.13. The standard deviations of postgraduates' score in metacognitive knowledge, metacognitive experience and metacognitive strategy are less than those of undergraduates. Overall, the results indicate that no statistical significance ($p>0.05$) in metacognitive ability between undergraduates and postgraduates, and invalidate hypothesis a.

Table 2: Two-tailed t-test results for undergraduates and postgraduates' Sudoku scores.

Group	N	Mean	SD	Sig.(two-tailed)
Undergraduates	15	24.86	11.91	0.656
Postgraduates	15	27.14	15.57	

As shown in Table 2, the difference of undergraduates and postgraduates' Sudoku mean scores is 2.28. The results indicate no statistical significance ($p>0.05$) in Sudoku puzzle-solving ability between undergraduates and postgraduates, so hypothesis b is invalid.

3.2 Correlations of Sudoku score with other variables

The linear regression analysis was used to analyze the correlations of Sudoku score with other variables (Table 3).

Table 3: Coefficient[a] of linear regression results for correlations of Sudoku scores with other variables.

Model	Unstandardized Coefficients		t	Sig.
	B	Standard Error		
（Constant）	-8.721	25.537	-0.342	0.736
Sex	3.448	5.322	0.648	0.524
Grade	2.482	5.012	0.495	0.625
The number of done Sudoku puzzles	8.689	3.108	2.796	0.011*
Average math scores in senior high school	1.377	4.865	0.283	0.780
Metacognitive knowledge	1.701	1.093	1.556	0.134
Metacognitive experience	-1.710	1.141	-1.499	0.148
Metacognitive strategy	-0.041	0.286	-0.143	0.888

a. Dependent variable: Sudoku score
*$p<0.05$

Data in Table 3 indicates that only the number of done Sudoku puzzles before the study has a significant effect on Sudoku score ($p<0.05$), and metacognitive ability has no significant effect on Sudoku puzzle-solving ability. Hypothesis c is invalid.

The linear regression analysis was used to analyze the correlations of Sudoku score with the number of done Sudoku puzzles before the study, as ANOVA results shown in Table 4.

Table 4: ANOVA[a] results for correlations of Sudoku scores with the number of done Sudoku puzzles.

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	1379.710	1	1379.710	9.567	0.004[b]
Residual	4038.049	28	144.216		
Total	5417.759	29			

a. Dependent Variable: Sudoku score
b. Predictors: (Constant), the number of done Sudoku puzzles before the study

Data in Table 4 shows that the number of done Sudoku puzzles before the study can be used to predict Sudoku score. The linear regression equation is $Y = 14.246 + 7.668\ X$.

Wenling Li et al. (2008) divided correlativity into four levels according to Pearson correlation coefficient: (a) No correlation or weak correlation, (b) normal correlation, (c) high correlation, and (d) strong correlation. Pearson correlation coefficient for all variables shows that Pearson correlation coefficient of Sudoku score and the number of done Sudoku puzzles before the study is 0.505, which

means the two variables have high correlativity. Pearson correlation coefficient of average math scores in senior high school and Sudoku score is 0.092, which means that these two variables have no correlativity. So hypothesis d is invalid.

3.3 Interview results

According to the results of metacognitive ability questionnaire, there were 20 participants hadn't done any Sudoku puzzles, 11 undergraduates, 9 postgraduates. 17 participants who hadn't done any Sudoku puzzles before answered this question. 12 of them said they wanted to do, 3 said they didn't want to do any more, 2 said they might want to do. 9 participants who had done some Sudoku puzzles before answered this question. 5 of them said they wanted to do.

4. Discussion

4.1 Average math scores in senior high school and Sudoku score

On the basis of this study results, there is no correlation between average math scores in senior high school and Sudoku score. So that we doubt whether it is worth students' while solving Sudoku puzzle at math class regularly. Class time is very important for students. If solving Sudoku puzzle cannot improve students' ability or scores, maybe school should reconsider how to help students make better use of class time.

However, we cannot draw the conclusion that solving Sudoku puzzles can't improve math abilities as this study has several limits. (a) This study only include average math scores in senior high school, not including math scores in junior high school and primary school. So it is illogical to say that solving Sudoku puzzles cannot improve math scores. (b) We divided average math scores in senior high school into five score section which is not a subtle rational division. (c) We gave only 9 puzzles to participants and they did Sudoku puzzles just for 1 hour. They cannot form a steady Sudoku puzzle-solving ability in such a short time, so the data maybe represents participants' ability accurately.

In the future, we can conduct a long-term tracking study in primary school and junior high school to explore whether solving Sudoku puzzles has impact on math scores.

4.2 The number of done Sudoku puzzles before the study and Sudoku score

According to the result, the number of done Sudoku puzzles before the study has a significant impact on Sudoku score. We can infer that to some extent, the larger number of Sudoku puzzles a participant had done the more experience and strategies he might get, and he would get the higher Sudoku score in the study. However, we should consider whether a certain number may exist. Participants may get equivalent scores when they had done more than the certain number of Sudoku puzzles. This requires a deeper study.

4.3 Metacognitive ability and Sudoku score

The results show that there is no significant difference in metacognitive ability between undergraduates and postgraduates. A possible reason is that two groups of participants are adults and in the stage of formal operational stage defined by Piaget. They have a steady cognitive level, and there is no significant difference in metacognitive ability among them. Another possible reason is that the metacognitive ability questionnaire doesn't work well to detect the metacognitive level.

Data show that metacognitive ability has no statistical significant effect on Sudoku score. However, we can't draw the conclusion that metacognitive ability has no significant impact on Sudoku puzzle-solving ability, because we don't have clear evidence that metacognitive ability of mathematical problem-solving is the same with metacognitive ability in Sudoku puzzle-solving. The metacognitive ability questionnaire detects the former not the latter. It is necessary to design a special scale to test metacognitive ability in Sudoku puzzle-solving in further study.

4.4 Attitude towards Sudoku puzzles

According to results of interview question, although 71.4 % of participants who had never done Sudoku puzzles before the study, 70.6% of them wanted to try it later. So we can speculate that Sudoku puzzle is an attractive game. Why is it so attractive? And why do some people think solving Sudoku puzzles is good for them improving ability subjectively? We can do another study to investigate the reason.

5. Conclusion

According to the study, there is no significant difference in metacognitive ability of mathematical problem-solving between undergraduates and postgraduates, and no significant difference in Sudoku puzzle-solving ability between undergraduates and postgraduates. Besides, metacognitive ability of mathematical problem-solving has no appreciable effect on Sudoku puzzle-solving. In addition, average math scores in senior high school have no positive correlation with Sudoku puzzle-solving ability. However, the number of done Sudoku puzzles before the study has a significant effect on Sudoku puzzle-solving ability.

There were limitations in the study. We had a small number of participants and more proper materials should be used.

Acknowledgements

This study thanks sincerely to professor Keding Zhong for his guidance and suggestion to study goals and data analysis method, Yehui Wang for detailed advice on data analysis and discussion, and vice professor Yin Wang for her kindness to provide research facility. Besides, we thank to the 32 participants.

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