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Comparing Elementary Students' Problem-Solving Behavior Patterns Using Lag Sequential Analysis

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Abstract: This paper investigated the elementary students' problem-solving behavior patterns using the lag sequential analysis. 90 students in grade 5 were required to develop their own strategies to find the solution to the task in an online assessment system and all their interactive behaviors were automatically recorded and then coded for further behavior analysis. Comparing the results between the higher-score students and lower-score students in the task showed that regardless of the prior knowledge and school subject performance, the behavioral patterns representing different problem-solving strategies determined student problem-solving competence and it provides implications for developing student problem-solving skills through strategy and character training.

Keywords: problem solving, assessment task, behavioral pattern, lag sequential analysis, elementary students

1. Introduction

Problem solving refers to the process of discovering proper method of reaching a goal from an initial state. Knowing how to use strategies to solve practical problems has become a necessary skill in the 21st century (Griffin, McGaw, & Care, 2012). While educated adults may show equally good performance in their skills to solve problems, teenager students normally have different competence levels in using strategies to solve problems (Findings, 2014).

In recent years, some scholars have concentrated on assessing problem solving. Distlehorst et al. (2005) assessed students' problem solving by checking their performance in information acqisition, self-regulation and collaborative study in problem-based learning (PBL) by grading reports submitted by students. Johnson et al. (2007) argued how students value the information can be evaluated through their information-accessing behaviors. Schweizer et al. (2013) developed MicroDYN to evaluate students' determining variable dependencies through manipulating the variables and observing the effects in a complex and dynamic environment. Mislevy (1994) came up with the fundamental concept of evidence-centered design (ECD) to build an environment to collect students' behavioral data and analyze their intentions.

Scholars also investigated different factors influencing problem-solving performance. Kalyuga et al. (2010) and Greiff et al. (2015) argued that cognitive elements, such as exploring the problem, representing knowledge, and planning and evaluating the solution affect problem-solving skills. Sabourin et al. (2012) discovered that information gathering could improve problem-solving efficiency. OECD (2012) found that non-cognitive factors such as belief and motivation have direct impact on problem solving process in the 2012 PISA results. Gyöngyvér et al. (2018) concluded that deductive and inductive ability and fluid intelligence level are significantly associated with problem solving.

In this paper, we aimed to check whether the above-mentioned factors make a difference in students' problem-solving process by analyzing their behavioral data representing problem-solving strategies. Our hypothesis is that more diversified strategical behaviors can result in better performance in problem solving and lag sequential analysis (Sackett & Richard, 1979; Bakeman & Gottman, 1986) is used to mine the behavioral data.

Because of the advance in information technology, hardware and software are competent to collect continuous real-time behavior data and software tools are available in identifying behavioral sequences in the data. Recently, scholars employed lag sequential analysis in learning analytics. Lan et al. (2012) used lag sequential analysis to identified the student knowledge construction behavior pattern in online asynchronous discussion. Hou (2013) analyzed the behavioral differences between students of different genders, prior knowledge, and learning performance in an educational MMORPG. Yang et al. (2015) investigated behavioral pattern and group interactive network of students in online English-to-Chinese cooperative translation activities without teacher's intervention. Malmberg et al. (2017) examined temporal sequences of regulated learning events during different stages of collaborative learning by conducting lag sequential analysis of video data of a two-month math course.

2. Assessment Environment

A general framework for assessment tasks is provided in the assessment system and functionalities that support recording student interaction are also implemented. One assessment task may consist of different task items including the multiple-choice question, fill-in-blank question or interactive question. The principle of the task design is that referring to relevant information (tips and reference information) provided in the system is essential for completing the task so that insights into respondents' interaction with the necessary information can be obtained.

To support the assessment, the system offers some general functionalities, as Figure 1 illustrates. For instance, an "Information Center" button is placed to the upper right of the task window and all the reference information associated to the current assessment task is stored in that component whereas some information is relevant but some are not. Besides, a tip button is to the upper left of the task window and a small popup window showing the guideline and tips about this task will be displayed after clicking it. In addition, the restart and give up buttons are to the lower left and right of the task window, respectively. Respondents can click the restart button to reload the page and restart the current task item from the beginning and the give up button to abort the current task item with zero score obtained. No task item can be directly skipped and the give up button will only be available several minutes after the current task item has been loaded and at least one action has been done.

Figure 1. General Functionalities of the Assessment System

We carried out our experiment and data analysis by using one of our assessment tasks where tent allocation in outdoor camping is used as the background setting. Respondents need to allocate tents to people by dragging women, girls, men or boys into the big, medium and small tents. Different tents can accommodate different numbers of people and two essential requirements for completing this task can only be found in the tip popup, as Figure 2 shows. The first rule is that only people of the same gender can use the same tent and the other is that each tent must have at least one adult in it. In addition, no prior knowledge is necessary and there is nothing relevant with this task in the "Information Center".

Besides, the dragging action in this task can never be undone and the only way of clearing a false move is to click the restart button and do the task again.

Figure 2. Tip Popup and the Essential Requirements

3. Experiment Design and Analysis Method

The experiment is designed into two stages. First, respondents needed to go through the pilot task which stays elementary but guides them through the system environment and functionality. Then, the main assessment task can be started and respondents would independently finish the task within 10 minutes. In total, 90 elementary students in grade 5 took part in this experiment.

In order to understand how elementary students solve problems from the perspective of behaviors sequences and discover whether there are significant differences in behavioral patterns between the higher-score group and lower-score group, we use lag sequential analysis to mine the student behavior sequences both in the whole problem-solving process and their choices of people and tents in allocating the tents.

For the whole process, all important problem-solving behaviors including reading the tip, dragging people into the tent, clicking the restart button, reading reference information, using the give up button and finally submitting the solution are recorded on the HTML5 webpage and then coded for further analysis, as Table 1 shows.

For the allocating strategy, only dragging people into the tent is analyzed but dragging different people (man, woman, boy and girl) to different tent (big, medium and small ones) is coded as different behaviors, as Table 2 shows. Since there may be hundreds of dragging actions for one student during the task and not all of them are useful, we only recorded who students dragged and which tent they dragged people into at the very beginning of the task and each time after they restarted the task by clicking the restart button. We believed that their first choice of both people and tents at every restart of the task is powerful enough to reveal students' problem-solving strategies by providing us insights into whether and how they changed strategies for each new attempt. Since no false move can be undone in the task and restart usually means there is somethings wrong, whether students would change their dragging strategies in the new turn can be really meaningful.

Table 1

The Coding Scheme for All the Behaviors in the Whole Problem-solving Process

Code	Behavior	Description
TP1	Read the tip	Read the tip at the beginning of the task
TP2	Click the tip	Read the tip during the problem-solving process by clicking the tip button
DR	Drag people	Drag people into the tents
RE	Click restart	Click the restart button to clear and reload the current task

DA	Use reference	Click the “Information Center” to read reference information
GU1	Click give up	Click the “Give up” button and the popup menu appears
GU2	Confirm give up	Confirm aborting the task in the popup menu with zero score obtained
CT	Click continue	Click the “Continue” button and return back to the current task
SU	Click submit	Click the submit button to submit the solution

Table 2

The Coding Scheme for Dragging Different People into Different Tents in Each New Turn

Code	Behavior	Description
WB	Woman-big tent	Drag a woman into the big tent
WM	Woman-medium tent	Drag a woman into the medium tent
WS	Woman-small tent	Drag a woman into the small tent
GB	Girl-big tent	Drag a girl into the big tent
GM	Girl-medium tent	Drag a girl into the medium tent
GS	Girl-small tent	Drag a girl into the small tent
MB	Man-big tent	Drag a man into the big tent
MM	Man-medium tent	Drag a man into the medium tent
MS	Man-small tent	Drag a man into the small tent
BB	Boy-big tent	Drag a boy into the big tent
BM	Boy-medium tent	Drag a boy into the medium tent
BS	Boy-small tent	Drag a boy into the small tent

Then, lag sequential analysis was conducted to analyze these behaviors. The GSEQ software is used to carry out behavior frequency analysis and sequential analysis. Then, we analyzed the relationship between the behavior pattern and task performance to discover whether there are significant differences in behavioral patterns between the higher-score and lower-score groups.

4. Results

4.1 Correlation Results

During our experiment, we also collected the Chinese and Math scores of the students in the last final exam. Then Pearson correlation coefficients were calculated to check whether their Chinese and Math exam scores can affect their assessment task performance. Table 3 showed the results and different Chinese and Math scores did not result in significant differences in task performance.

Table 3

Correlation Between the Exam Scores and Assessment Task Performance

	Chinese score	Math score	
Pearson correlation	0.13	0.05	Task performance
P-value	0.2827	0.6465	Task performance

4.2 Results of the Lag Sequential Analysis

Since our assessment task requires no prior knowledge and students’ performance was also independent from their school scores, we assume that the only possible factor determining students’ task performance may be their problem-solving behaviors and strategies during the task process and therefore, the lag sequential analysis of their behaviors in completing the task is conducted.

The full mark of the task is 100 and the average score of the students is 56.3. In all the 85 students from whom valid behavioral data was obtained, 49 obtained higher scores than the average while 36 got lower scores. As a result, the students were divided into two groups in the behavioral sequential analysis and the results are as follows.

4.2.1 All the Task Behaviors

The sequential analysis was conducted for all the task behaviors and students in difference groups have their own significant behavior sequences, as Table 4 and 5 show.

Table 4

Adjusted Residuals Table (Z-scores) of All the Problem-Solving Behaviors for the Higher-Score Group

	DR	GU1	GU2	CT	RE	TP1	TP2	SU	DA
DR	-15.26	-0.95	0	-0.95	9.55	0	0.53	8.5	-0.9
GU1	-0.9	-0.06	0	17.86	-0.72	0	-0.15	-0.45	-0.11
GU2	0	0	0	0	0	0	0	0	0
CT	-0.9	-0.06	0	-0.06	1.39	0	-0.15	-0.45	-0.11
RE	10	-0.72	0	-0.72	-5.79	0	0.49	-5.81	-0.39
TP1	7.71	-0.41	0	-0.41	-5.21	0	-1.08	-3.27	0.63
TP2	2.46	6.24	0	-0.16	-2.06	0	-0.43	-1.29	-0.32
SU	0	0	0	0	0	0	0	0	0
DA	-0.8	-0.11	0	-0.11	0.67	0	-0.3	-0.91	4.3

Table 5

Adjusted Residuals Table (Z-scores) of All the Problem-Solving Behaviors for the Lower-Score Group

	DR	GU1	GU2	CT	RE	TP1	TP2	SU	DA
DR	-13.07	2.85	-4.48	-3.61	13.91	0	0.31	3.02	0.8
GU1	-5.12	-2.32	14.63	11.81	-5.18	0	-0.85	-0.92	-0.6
GU2	0	0	0	0	0	0	0	0	0
CT	-1.54	6.85	-1.07	-0.86	-1.58	0	-0.52	-0.56	-0.37
RE	16.14	-3.83	-3.94	-3.18	-9.65	0	-0.22	-2.08	-0.16
TP1	2.63	-0.7	-0.53	-0.43	-1.56	0	-0.26	-0.28	-0.18
TP2	0.67	-0.85	-0.65	-0.52	-0.21	0	2.96	-0.34	-0.22
SU	0	0	0	0	0	0	0	0	0
DA	2.27	-0.6	-0.46	-0.37	-1.35	0	-0.22	-0.24	-0.16

Figure 3 and 4 present all the behavior sequences in Table 4 and 5 which reached a level of significance (with Z-scores bigger than 1.96). The TP2 → DR sequence in the higher-score group suggests that higher-score students tended to turn to tip for help during the problem-solving process and then probably used the information they obtained to do dragging while the TP2 → TP2 sequence in the lower-score group without TP2 → RE or TP2 → DR sequences shows these students would repeat reading the tip but the tip information seems useless for their dragging.

Although the reference information can provide nothing helpful for this task, the DA → DA sequence in the higher-score group represents these students' active efforts in searching the reference for useful information again after their previous attempt while the DA → DR sequence in the lower-score group shows these students would just gave up searching for information and then did dragging; the GU1 → CT sequence in the higher-score group reveals that the students may click the give up button but they tended to return back to the task whereas the GU1 → GU2 sequence for the lower-score students tells us they probably really gave up.

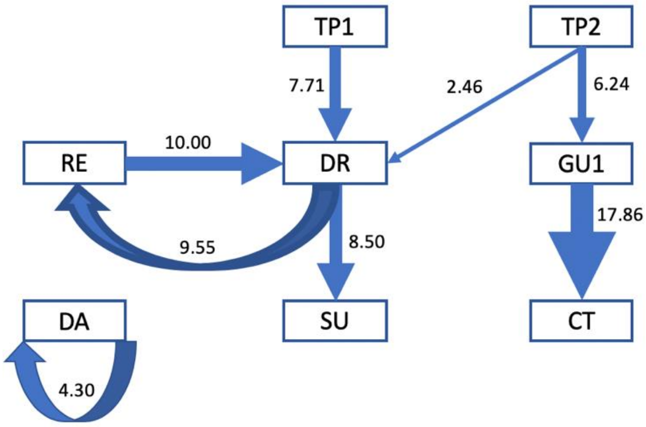

Figure 3. Behavioral Transition Diagram of All the Problem-Solving Behaviors for the Higher-Score Group

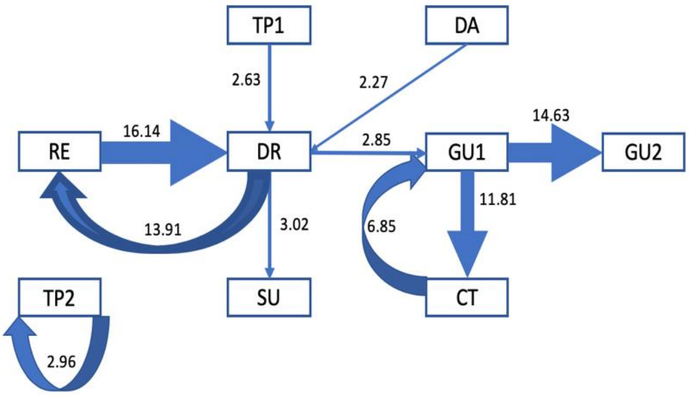

Figure 4. Behavioral Transition Diagram of All the Problem-Solving Behaviors for the Lower-Score Group

4.2.2 The Various Dragging behaviors

The sequential analysis was conducted for students' various dragging behaviors and students in difference groups have their own significant behavior sequences, as Table 6 and 7 show.

Table 6

Adjusted Residuals Table (Z-scores) of the Various Dragging Behaviors for the Higher-Score Group

	WB	WM	WS	GB	GM	GS	MB	MM	MS	BB	BM	BS
WB	3.79	-0.07	-1.48	0.35	-0.68	0.35	-1.65	-0.42	-1.72	-0.85	1.19	-2.32
WM	0.13	0.59	-0.64	0.85	0.85	-0.74	-0.58	0.39	-0.74	-0.37	-0.37	0.22
WS	1.14	-0.24	-0.18	-0.21	-0.21	-0.21	-0.42	-0.26	-0.21	-0.1	-0.1	-0.29
GB	-1.59	-0.79	1.3	-0.71	-0.71	-0.71	1.42	0.49	-0.71	2.91	-0.35	1.6
GM	-0.04	-0.65	1.74	-0.58	-0.58	3.31	-1.15	-0.72	1.37	-0.29	-0.29	-0.78
GS	-2.23	3.16	1.94	-0.53	1.56	-0.53	-1.06	-0.66	1.56	-0.26	-0.26	0.89
MB	-0.65	-0.75	-0.57	1.07	-0.67	-0.67	1.63	0.61	1.07	-0.33	-0.33	-0.89

MM	-1.8	-0.48	-0.37	-0.43	2.1	-0.43	2.02	1.56	-0.43	-0.21	-0.21	-0.58
MS	0	0	0	0	0	0	0	0	0	0	0	0
BB	-0.88	-0.24	-0.18	-0.21	-0.21	-0.21	2.4	-0.26	-0.21	-0.1	-0.1	-0.29
BM	-0.88	-0.24	-0.18	-0.21	-0.21	-0.21	-0.42	-0.26	-0.21	-0.1	-0.1	3.54
BS	-1.09	-0.54	-0.42	-0.48	-0.48	-0.48	0.33	-0.6	1.79	-0.24	-0.24	2.85

Table 7

Adjusted Residuals Table (Z-scores) of the Various Dragging Behaviors for the Lower-Score Group

	WB	WM	WS	GB	GM	GS	MB	MM	MS	BB	BM	BS
WB	2.83	-1.59	0.09	1.24	-1	-2.14	-1.36	1.15	1.07	-1.23	0	-1.11
WM	-0.7	2.76	-0.48	-1.06	0.36	0.73	-0.14	-0.69	-0.34	-0.77	0	-0.03
WS	-1.36	-0.46	5.52	-0.4	-0.35	-0.29	-0.44	-0.26	-0.13	3.36	0	-0.42
GB	-0.2	-1.01	-0.4	0.48	-0.76	-0.63	1.49	-0.56	-0.28	-0.63	0	1.65
GM	-0.72	-0.81	-0.32	-0.7	3.04	-0.51	-0.78	-0.45	-0.22	1.63	0	0.81
GS	0.49	-1.01	-0.4	-0.86	-0.76	4.68	-0.96	-0.56	-0.28	-0.63	0	0.37
MB	-0.2	-1.01	-0.4	-0.86	0.76	-0.63	1.49	-0.56	-0.28	-0.63	0	1.65
MM	-1.56	3.46	-0.32	-0.7	-0.61	1.63	0.71	-0.45	-0.22	-0.51	0	-0.74
MS	0	0	0	0	0	0	0	0	0	0	0	0
BB	-1.94	1.07	-0.26	1.41	-0.49	-0.41	1.17	2.53	-0.18	-0.41	0	-0.6
BM	0	0	0	0	0	0	0	0	0	0	0	0
BS	-0.89	0.17	-0.4	0.48	0.76	-0.63	0.26	-0.56	-0.28	2.91	0	-0.91

Figure 5 and 6 present all the behavior sequences in Table 6 and 7 which reached a level of significance (with Z-scores bigger than 1.96). It is obvious that higher-score students tried more combinations of people and tents to find the task solution through trial and error while their lower-score peers tended to insist on their choices without many adjustments.

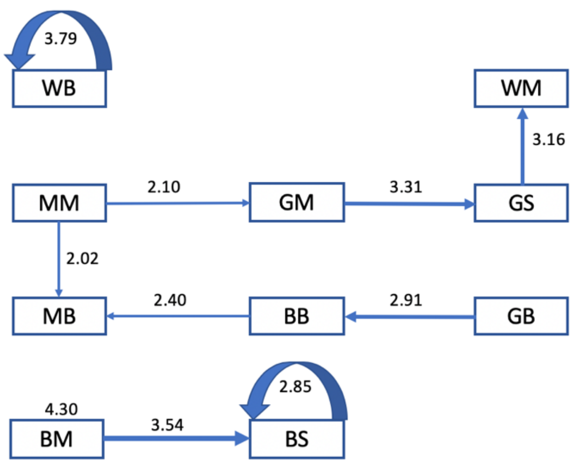

Figure 5. Behavioral Transition Diagram of the Various Dragging Behaviors for the Higher-Score Group

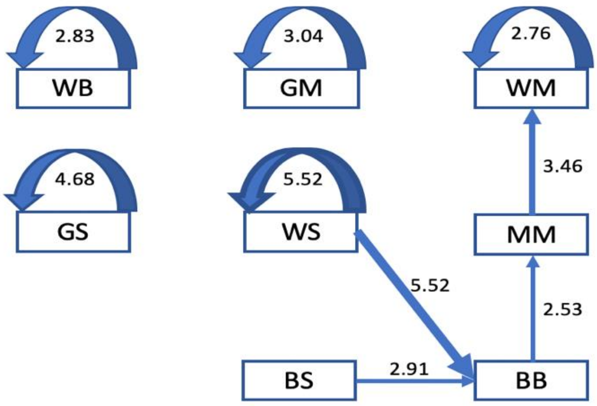

Figure 6. Behavioral Transition Diagram of the Various Dragging Behaviors for the Lower-Score Group

5. Discussion and Conclusion

We can draw several implications from this study. First, disciplinary knowledge has slight influence on the domain-general problems as the Pearson correlation results shows and poor-performance students may be competent to achieve satisfactory results in the problem-solving task.

Second, strategical factors including understanding necessary rules, information searching, and applying trial and error can actually play the fundamental role in problem solving as the significant behavior sequence suggested.

Third, the emotional attitude may also affect the problem-solving performance and some lower-score students failed simply because they easily gave up rather than persevered, and behaved blindly without thinking twice while higher-score students were more willing to stay the course in spite of difficulty and they also made better use of all potentially useful information including the tip and reference. This implies that developing students' problem-solving competence can use strategy and character training as well.

Based on the behavioral patterns revealed in our analysis, this study found that regardless of the prior knowledge and school subject performance, it can be the behavior patterns determined by problem-solving strategies that shape students problem-solving competence.

References

Bakeman, R., & Gottman, J. (1986). *Observing interaction*. New York: Cambridge University Press.

Distlehorst, L. H., Dawson, E., Robbs, R. S., & Barrows, H. S. (2005). Problem-based Learning Outcomes: The Glass halffull. *Academic Medicine*, *80*(3), 294-299.

Findings, K. (2014). PISA 2012 Results: Creative Problem Solving: Students' Skills in Tackling Real-life Problems (volume V). *OECD*.

Greiff, S., Wüstenberg, S., & Avvisati, F. Computer-generated log-file analyses as a window into students' minds? A showcase study based on the PISA 2012 assessment of problem solving[J]. *Computers & Education, 2015*,91: 92-105.

Griffin, P., McGaw, B., & Care, E. (2012). *Assessment and Teaching of 21st Century Skills:* Springer.

Gyöngyvér, Molnár, Greiff S, Fischer A, et al. Empirical study of computer-based assessment of domain-general complex problem-solving skills[M]. *The Nature of Problem Solving*. 2018.

Hou, H. T., & Wu, S. Y. (2011). Analyzing the Social Knowledge Construction Behavioral Patterns of an Online Synchronous Collaborative Discussion Instructional Activity Using an Instant Messaging Tool: A Case Study. *Computers and Education*, *57*(2), 1459-1468.

Johnson, E. J., Häubl, G., & Keinan, A. (2007). Aspects of endowment: A Query theory of value construction. *Journal of Experimental Psychology Learning Memory & Cognition*, *33*(3), 461-474.

Kalyuga,S., Renkl, A., Paas, F., Facilitating Flexible Problem Solving: A Cognitive Load Perspective[J]. *Educational Psychology Review, 2010*(22):175-186.

Lan, Y. F., Tsai, P. W., Yang, S. H., & Hung, C. L. (2012). Comparing the Social Knowledge Construction Behavioral Patterns of Problem-based Online Asynchronous Discussion in E/M-learning Environments. *Computers & Education*, *59*(4), 1122-1135.

Malmberg, J., Järvelä, S., & Järvenoja, H. (2017). Capturing temporal and sequential patterns of self-, co-, and socially shared regulation in the context of collaborative learning. *Contemporary Educational Psychology, 49*, 160-174.

Mislevy, R. J. (1994). Evidence and Inference in Educational Assessment. *Psychometrika*. *1995*(4), 44.

Sabourin J, Rowe J, Mott. B. W, et al. Exploring inquiry-based problem-solving strategies in game-based learning environments[C]. *International Conference on Intelligent Tutoring Systems*. Springer-Verlag, 2012:470-475.

Sackett, G. P., & Richard Holm (1979). A fortran program for lag sequential analysis of contingency and cyclicity in behavioral interaction data. *Behavior Research Methods and Instrumentation, 11*(3), 366-378.

Schweizer, F., Wüstenberg, S., & Greiff, S. (2013). Validity of the MicroDYN approach: Complex problem solving predicts school grades beyond working memory capacity. *Learning & Individual Differences, 24*(2), 42-52.

Yang, X., Li, J., Guo, X., & Li, X. (2015). Group Interactive Network and Behavioral Patterns in online English-to-Chinese Cooperative Translation Activity. *Internet and Higher Education*, *25*, 28-36.