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Analysis of Steps in Posing Arithmetic Word Problem as Sentence-Integration on Interactive Learning Environment

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Abstract: Learning by problem-posing is promising activity in learning mathematics and considered to contribute the understanding of the problem's structure. If we can clarify how learners are thinking in steps of problem-posing, we will support learning by problem-posing more. This study investigate what learners think during problem-posing as sentence-integration in terms of intermediate products as well as the posed problems as the resultant product. Problem-posing as sentence-integration defines that arithmetic word problems have a structure and problem-posing is a task to satisfy all the constraints and the requirements to build a valid structure. A previous study shows, in problem-posing of arithmetic word problems as sentence-integration, learners try to satisfy relatively large number of the constraints in the posed problems. This study focuses on the violation of constraints in the intermediate products during problem-posing as sentence-integration. If learners have concern with the structure, they will try to avoid relatively larger number of the violated constraints on the way to the resultant posed problems. We conducted Pearson's correlation test between the occurrence frequency of intermediate products and the number of violated constraints of them. The result shows the negative correlation between them. We consider that learners had an inclination to avoid as many violated constraints as possible throughout problem-posing activity.

Keywords: problem-posing activity, intermediate products, arithmetic word problems, learning analytics

1. Introduction

The development of problem-posing skills for learners is one of the main aims of mathematics learning and it should occupy a central role in mathematics activities (Crespo, 2003). Several investigations have confirmed that learning by problem-posing in conventional classrooms is promising activity in learning mathematics (Silver and Cai, 1996; English, 1998). In problem-posing, assessment of each posed problem and assistance based on it are necessary (Hirashima et al., 2007). Teacher assessment of posed problems encompasses learners' development of diverse mathematical thinking (English, 1997). Since learners are usually allowed to pose several kinds of problems, including a large range of them, it can be challenging for teachers to complete assessment and feedback for the posed problems in classrooms.

To address this issue, technology-enhanced approaches have been used and peer-assessment posed has been conducted to realize learning by problem-posing in a practical way, especially in regard to assessment and feedback. Self- and peer-assessed posed problems were conducted. A novel way for merging assessment and knowledge sharing using an on-line Question-Posing Assignment (QPA) has been examined (Barak & Rafaeli, 2004). A networked question-posing and peer assessment learning system enabling students to pose questions was developed (Yu and Pan, 2014). In contrast, diagnosis functions that can assess and give feedback to each posed problem automatically have been proposed (Nakano, Hirashima and Takeuchi, 1999; Hirashima, Nakano and Takeuchi, 2000). This automatic way of diagnosis-facility assessment is called agent-assessment. Furthermore, a learning environment system, named Monsakun, which practically use agent-assessment for one operation of addition and subtraction has been developed (Hirashima et al., 2007). The system has many assignments of problem-posing and requests learners to pose the required problem by combining three simple sentences from given sentences until they successfully pose the required one in each assignment. By using this system, the opportunity to pose the problems for learners increased, the feedback to learners according to their mistakes provided, and for teacher, checking the validity of posed problems becomes easier. This study aimed at the practical realization of agent-assessment in order to understand the process of learners' problem-posing, so that it could be analyzed.

Using Monsakun as a problem-posing learning environment, learners' ability to solve problems as well as understand them is promoted. In practical use and long-term evaluation, it was confirmed that learning by problem-posing with Monsakun is interesting and useful learning method even though learners have made many wrong answers (Hirashima et al., 2008). Lectures and exercises with Monsakun, improves learners' problem-posing as well as their problem-solving (Yamamoto et al., 2012). Through previous researches, the usefulness of Monsakun has been confirmed for learning by problem posing. Although posing problems in the learning environment is considered to contribute the understanding of the problems structure, it is not clear how learners think on the way to pose problems. Therefore, it is essential to investigate the learning activity for every step and to generate inferences of learners' thinking from their behavior in learning environments.

The basis of Monsakun is "Triplet Structure Model" (Hirashima, Yamamoto and Hayashi, 2014) that defines the structure of an arithmetic word problem as sentence-integration. This model deals with an arithmetic word problem that is solved by only one arithmetical operation. This is the fundamental unit of concept quantity representation and much more complex arithmetic word problems can be composed of the combination of the units (Hirashima et al., 2015a). An arithmetic word problem in this model is an integration of three sentences representing numerical concepts. In addition to that, the model defines constraints valid problems that have to be satisfied. When a learner can pose the required problem in Monsakun, the problem certainly meets the constraints. In other words, problem-posing in Monsakun is the division of the task to pose a such arithmetic word problem into two sub-tasks: generation and integration of three sentences satisfying the required constraints and the replacement of generation (sub-)task by selection task of sentences. This is the same as the concept of "kit-build concept map" and focus learner's thinking on the structure of learning content (Hirashima et al., 2015b).

Previous study reported that, although learners made many wrong answers to get the correct answer in some assignments, they attempted to pose problems satisfying as many constraints required in each assignment as possible (Hasanah, Hayashi and Hirashima, 2015). This means they are not posed the required problems randomly as well as their many wrong answers are not meaningless as the results of thinking. They tried to pose problems with thinking to satisfy constraints to form a valid problem based on their own understanding. In addition to their investigation of learners' answers as posed problems, we investigate the intermediate products on the way to posed problems. The assumption in this study is that learners trying to avoid violated constraints in the intermediate products based on their understanding, which is sometimes imperfect; while they try to use unnecessary sentences for the required problem, the arrangements are not meaningless in their thinking. They are also attempting to integrate sentences as many constraints required in each assignment as possible in each step. To prove this assumption, we defined the measure of constraints based on the model and checked the correlation between the violation of constraints and the frequency of each arrangement of sentence cards that the learners actually made. Therefore, we conducted analysis of learners' steps during problem-posing activities using Monsakun.

The composition of this paper is organized as follows. The next section gives an overview of Monsakun, followed by description of problem-posing activity in Triplet-structure model, and explanation of constraints in problem-posing activity on Monsakun. Section 3 shows the analyses, results and discussions. Finally section 4 concludes this paper and shows some promises of future study.

2. Problem-Posing Activity in Monsakun

2.1 Monsakun as Interactive Learning Environment for Problem-Posing

The interface of Monsakun is shown in Figure 1. In the problem-posing activity by using Monsakun, learners do not create their own problem statements, however they are required to interpret the sentence cards and integrate them into one problem in the card slots part. This activity is called "problem-posing as sentence-integration” (Hirashima and Kurayama, 2011). The system provides a set of sentence cards and a numerical expression in the requirement part, and then learners pose an arithmetical word problem based on triplet structure model using the numerical expression by selecting and arranging appropriate sentence cards.

Triplet-structure model defines an arithmetic word problem solved by addition or subtraction as a composition of three simple sentences with two “existence sentences” and one “relational sentence”. An existence sentence represents a number of single objects that has an independent quantity. A relational sentence has a relative quantity and contains keyword that represents a story type. Although an existence sentence can be used in any story, a relational sentence is used only in one specific story. There are four story types: combination story, increase story, decrease story, and comparison story.

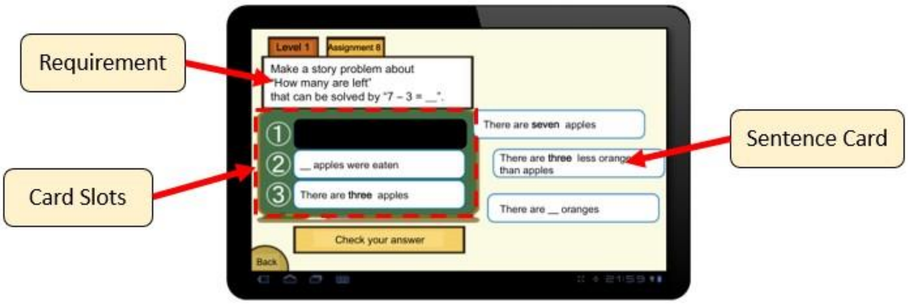

Figure 1. Interface of Monsakun.

2.2 *Problem-Posing Activity in Triplet-Structure Model*

Monsakun records learners' problem-posing activity as a combination of sentence cards in the card slots. The product of a problem-posing activity is a resultant of selecting and arranging a sentence card in the card slot or removing a sentence card from the card slot, which is called "state". When the product is composed of three sentence cards (the card slots is completely arranged), then it is called the "posed problem". An example of the posed problem condition is shown in Figure 2(c). Whereas when the product is not composed by three sentence cards, then it is called the "intermediate product" on the way to pose the problem. The examples of the intermediate product are shown in Figure 2(a) and Figure 2(b).

The sentence cards are encoded with indexing number shown in Figure 2(d). When the slot is still empty, index = 0 is implemented. For instance, when learners pose the problem by selecting sentence card #4 and arrange it into the second slot, state 040 has obtained, it is shown in Figure 2(a). Another example of state is shown in Figure 2(b), state 310 happens when learners pose the problem by selecting sentence card #3 then arranging into the first slot and selecting sentence card #1 then arranging into the second slot.

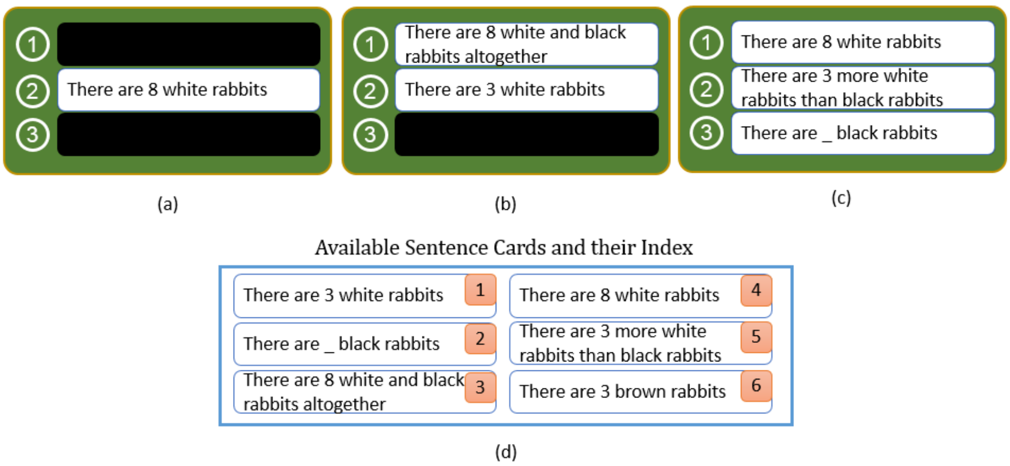

Figure 2. Example of states and the index of available sentence cards.

In order to complete an assignment, the learners attempt to arrange various combination of sentence cards, so that it will generate a particular state according to what they set. They arrange the composition until they reach the composition of correct problem. For instance, several steps performed by a learner shown in Figure 3. At the first time, state 000 has generated as initial state. In the first step, the learner begins with resulted state 010; this means that the learner selects the first sentence card and arranges it into the second slot. The second step, state 410 has composed, which means the learner selects the fourth sentence card and arranges it into the first slot. The next step, the learner removes the first sentence card from the second slot; this condition makes the state turned into state 400. Then, learner tries to pose the problem resulted in state 450, and so on, until the correct state are reached.

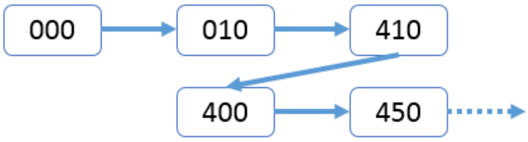

Figure 3. Several states generated from a learner's steps.

According to the model, all possible combinations of sentence cards and transitions among them could be clearly defined as a network of states. We call this network as "Problem States Space." All the steps of problem-posing in Monsakun could be mapped into a transition from a state to another in this network. All possible states which consists of three sentence cards index are obtained by combining all the available sentence cards, including the index=0. Each state represents a basic unit of thinking, and a problem state space provides the range of thinking in a problem-posing assignment. An example of all possible states from six available cards in a combination story is shown in Figure 4.

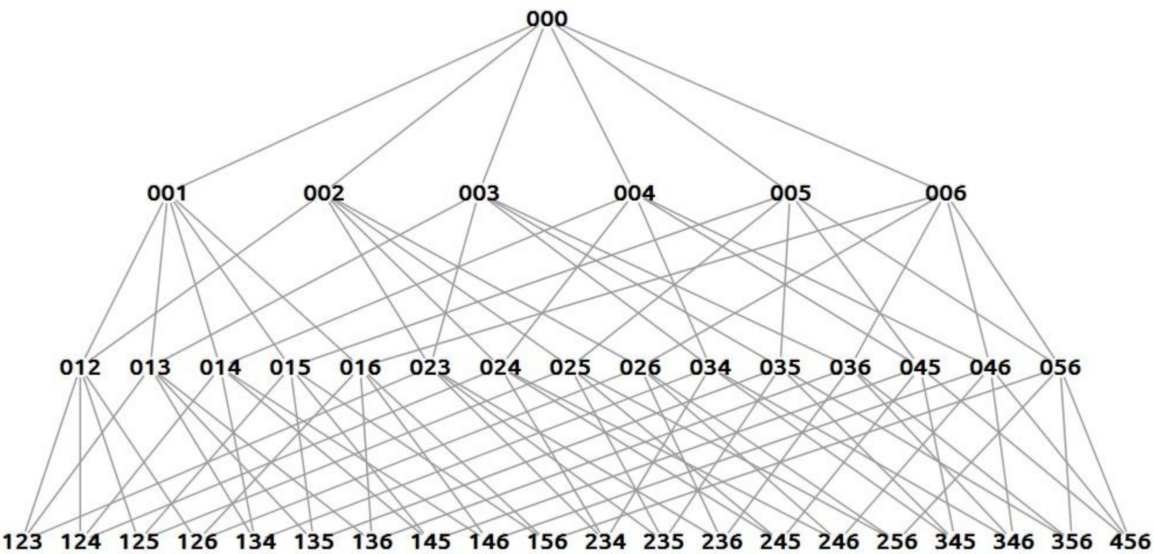

Figure 4. Problem state spaces of a combination story problem with six available sentence cards.

2.3 *Assessment of Products: Constraints to form a problem*

The task model of problem posing as sentence integration has been developed based on the consideration of problem types in the triplet structure model (Kurayama and Hirashima, 2010). Based on the task model, five main constraints to be satisfied by each posed problems have defined, which are: 1) Calculation, 2) Story type, 3) Number, 4) Objects, and 5) Sentence structure. Learners should complete these constraints to pose the required problem. When all the five constraints are satisfied, the learner has succeeded in posing a correct problem according to the assignment requirements. When less than five constraints are satisfied, the learner has acquired a level of understanding in the structure of arithmetic word problem, however, the learner does not satisfy the requirements yet. If there are no constraints satisfied by the learner, it shows that the learner is unable to understand the structure of arithmetic word problem.

According to the triplet structure model, actually we only can measure the validity of the posed problem products, which is based on the number of satisfied constraints. Therefore, in order to cover the measurement of the intermediate products, we define three values for each constraint: -1, 0, and 1. The value of -1 means the constraint is violated, the value of 0 means the constraint is not violated, and the value of 1 means the constraint is satisfied. The validity of product is calculated by summing all constrains value, and the number of violated constraints is obtained by counting how many constraints are violated. The example of several states from assignment 1 at level 5 and their satisfaction of constraints are presented in Table 1.

The requirement of the Assignment 1 at level 5 is: *Make a word problem about "How many are there overall" that can be solved by "8 - 3"*, which is an arithmetic word problem in combination story. There are six available sentence cards that could be used by learners. The sentences for each card are composed of: (1) There are 3 white rabbits, (2) There are _ black rabbits, (3) There are 8 white and black rabbits altogether, (4) There are 8 white rabbits, (5) There are 3 more white rabbits than black rabbits, and (6) There are 3 brown rabbits. There is no satisfied constraint, nor violated constraint at the first example state because it is possible to make calculation using sentence card in the state and it is not violated. The story type, number, object, and sentence structure also not violated. Therefore, all constraints in this state are assigned to 0. The second example is state 014, which violate the calculation constraint. Based on the numerical expression in the requirement, the number “8” should be on the relational sentence. However, sentence card #4 is an existence sentence card and it contains the number “8”. Therefore, this state violate the calculation constraint and this constraint is assigned to -1. The story type, number, object, and sentence structure are not violated, nor satisfied, because we still can’t decide it. Thus, the four constraints are assigned to 0. The last example satisfies one constraint, number. There is no story can be built from this composition, nor the calculation and sentence structure. It can be calculated and well-structured when it consists of two existence sentences and one relational sentence, instead of all sentence cards are existence cards. In addition, there is no relation between objects in the composition of sentence cards. They are independent objects consist of white, black, and brown rabbits. This condition causes the number of violated constraint is assigned to 4, because there are four constraints are violated. We calculate the validity values for all states and present the visualization that is shown in Figure 5. The graph in Figure 5 visualize the validity of states presented by the size of nodes. The nodes with the larger size have the higher validity than the nodes with the smaller size.

Table 1: The example of several states and their satisfaction of constraints.

<table>
<tr><th rowspan="2">No</th><th rowspan="2">States</th><th rowspan="2">Composition of sentence cards</th><th colspan="5">Constraint</th><th rowspan="2">Validity</th><th rowspan="2">Number of Violated Constraints</th></tr>
<tr><th>C1</th><th>C2</th><th>C3</th><th>C4</th><th>C5</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">001</td><td></td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">0</td></tr>
<tr><td></td></tr>
<tr><td>There are 3 white rabbits</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">014</td><td></td><td rowspan="3">-1</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">-1</td><td rowspan="3">1</td></tr>
<tr><td>There are 3 white rabbits</td></tr>
<tr><td>There are 8 white rabbits</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">246</td><td>There are _ black rabbits</td><td rowspan="3">-1</td><td rowspan="3">-1</td><td rowspan="3">1</td><td rowspan="3">-1</td><td rowspan="3">-1</td><td rowspan="3">-3</td><td rowspan="3">4</td></tr>
<tr><td>There are 8 white rabbits</td></tr>
<tr><td>There are 3 brown rabbits</td></tr>
</table>

C1: Calculation constraint, C2: Story type constraint, C3: Number constraint,
C4: Object constraint, C5: Sentence structure constraint

3. Analysis of Steps in Terms of Constraints

This section show the results of analyses of the intermediate products as well as the posed problem of problem-posing from Monsakun log data of a practical use in a classroom of 39 first grade students. The goal of this analysis is to answer the research question in this study whether learners are attempting to integrate sentences in avoiding the violated constrains on each step of posing the problem. To answer this question, we analyze the following two things: (1) the correlation between the number of violated constraints and the occurrence frequency of each state and (2) the proportion of the number of states and the occurrence frequency based on the number of violated constraints. If they try to avoid the violated states, on the way to posed problem, the correlation is negative and the proportion of occurrence is lower than states.

In this section, the results and the analyses of Monsakun log data from a practical use in a classroom of 39 first grade students is reported. In the practical use, learners used Monsakun as an introduction of problem-posing (5-10 min) at the beginning of a class. Then, the learners were taught the problem structures by the teacher on the blackboard using several sentence cards that are parts of problems (20-35 min). In that time, the teacher provided one assignment to all learners that resembled problem-posing process in Monsakun and encouraged participation and active discussion from all learners to pose the correct problem together. Finally, at the end of class, learners were using Monsakun to exercise in posing the problems (5-10 min). Monsakun has levels of problems that require different thinking approach. Each learner challenges 12 assignments in the level of Monsakun.

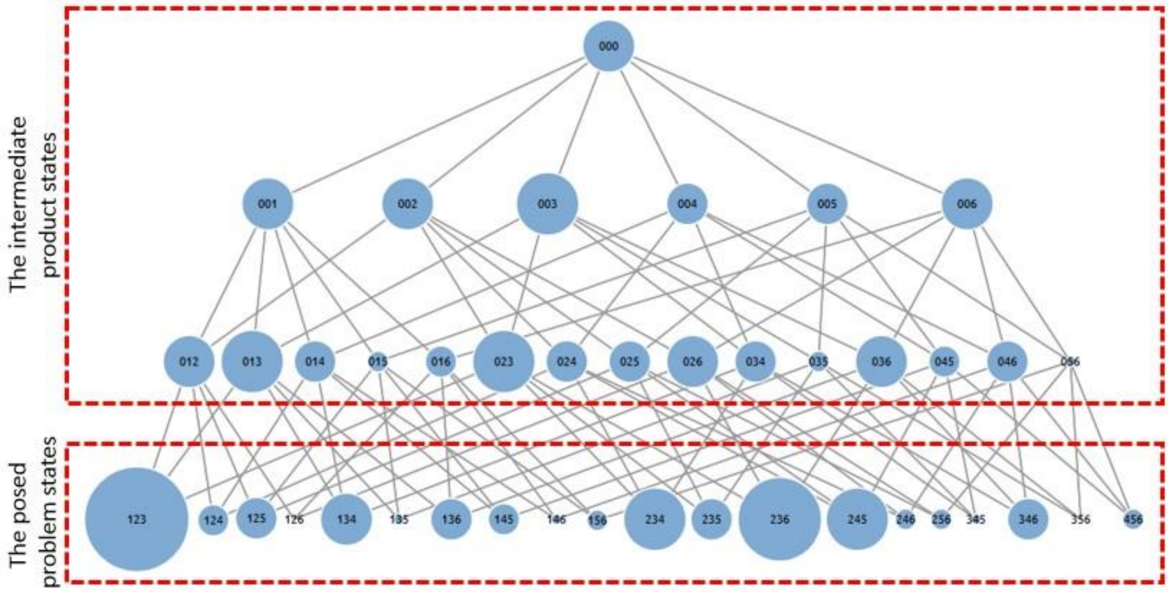

Figure 5. The visualization of the validity of products in Assignment 1 at Level 5.

The analysis of learners' performance by looking at the average steps and mistakes in posing the problems on Monsakun has been reported (Hasanah, Hayashi and Hirashima, 2015). The average of steps and mistakes shows how many steps a learner needed in order to pose a correct problem in one assignment and how many mistakes the learner made during the process, respectively. Ideally, a learner would only need 3 steps to pose a correct problem, because a problem in Monsakun consists of the arrangement of 3 simple sentence cards. The result shows that the average of steps and mistake in Level 5 was very high compared to the others, which shows that Level 5 was indeed very challenging for learners. In this study, investigation of every step of learners during pose the problems is conducted, which means the intermediate product states as well as the posed problem states arranged by learners is inspected in order to check that learners attempt to arrange valid composition of sentence cards in the middle of problem-posing activity at Level 5.

3.1 Analysis of Learners' Steps in Level 5

In this section, the result of analysis steps in Level 5 is explained. The analysis investigates states performed by learners which represent their steps and conducts correlation analysis between number of steps and number of violated constraints. The result of this analysis will provide the answer of the research question.

In Monsakun, five or six sentence cards are provided in each assignment. Three of them are correct cards, which satisfy all constraints from the assignment requirement and when composed correctly will form the correct problem. The rest are dummy cards, which designed through careful considerations by an expert as a meaningful distraction to the learners in order to learn the structure of simple arithmetic word problem. Despite the nature of this learning system could permit learners to select three sentence cards randomly, learners' intention in posing problems according to the given requirements is explained through the correlation analysis between occurrence frequency of products and validity of product for each arranged state in Level 5. Here, occurrence frequency of a state shows the frequency of states that is actually arranged by learners in order to pose a correct problem in one assignment. While the number of violated constraints of a state shows how many constraints are violated based on the state. We would like to check the occurrence frequency of each intermediate products and the correlation with constraint violated in it. If the number of violated constraints has a negative correlation to the frequency, then the high number of violated constraints will be followed by the lower number of steps. It would show that the high number of violated compositions of sentence cards have a small number of learners' steps. Therefore, this correlation test will strengthen our assumption that learners attempt to avoid compositions of sentence cards that cause high number of violation even on the way to posed problem.

In this analysis, we conduct a Pearson's correlation test between the occurrence frequency of products and the number of violated constraints in intermediate and posed problem products for each arranged state in Level 5. However, we omit assignments from fourth to ninth because of the design of the sentence cards, all the products satisfy at least one constraint by default. The goal of this study is to check whether learners make meaningless intermediate products or not even on the way to posed problems.

The result is shown in Table 2. Significant correlation ($p<0.05$) in five out of six assignments is found, which shows that many steps performed by learners had an inclination to avoid as many violated constraints as possible. The highest correlation is in Assignment 2 (rho = -0.5338, $p<0.01$) and the scatterplot of this assignment shown in Figure 6(a). The red line in the scatterplot shows the regression line of the data. Based on this information, the frequency of each intermediate product has the negative correlation with constraints violated in it. It supposed that learners attempted to arrange the problem in avoiding more violated constraints. If the learners posed problem randomly, the distribution of number of learners' steps would not have a significant difference than the violated constraints. This finding shows that learners had an inclination to pose more valid intermediate products.

Furthermore, the result of correlation in Assignment 3 shows marginal difference ($p<0.1$). The scatterplot of correlation in Assignment 3 shown in Figure 6(b) indicates that the learners seem to little hard in avoiding violated constraints. With that reason, further analysis is observed.

Table 2: Correlation between the occurrence frequency of products and number of violated constraints in Level 5.

Assignment	Pearson's Correlation	p-value
1	-0.3071 *	0.0479
2	-0.5338 **	0.0007
3	-0.3897 +	0.0730
10	-0.5869 **	0.0016
11	-0.5570 **	0.0011
12	-0.4640 **	0.0050

**: significant correlation ($p<0.01$), *: significant correlation ($p<0.05$), +: marginal correlation ($p<0.1$)

3.2 Analysis of Proportion of Violated Constraints at Level 5

In this section, we discuss the proportion of occurrence frequency and number of states based on the number of violated constraints. Here, number of states means the number of card combination that is possibly arranged by the learners. We check the number of states that categorized in each number of violated constraints and the occurrence frequency that arranged by learners. We would like to show that although the correlation between the occurrence frequency and the number of violated constraints is not significant, there is significant difference between the number of states and the occurrence frequency of them. The result of correlation analysis and detail proportion of the assignments investigated in this study presented in Table 3. We found significant difference in four out of six assignments ($p<.01$), which shows that learners made a conscious attempt to avoid more violated constraints in the assignments.

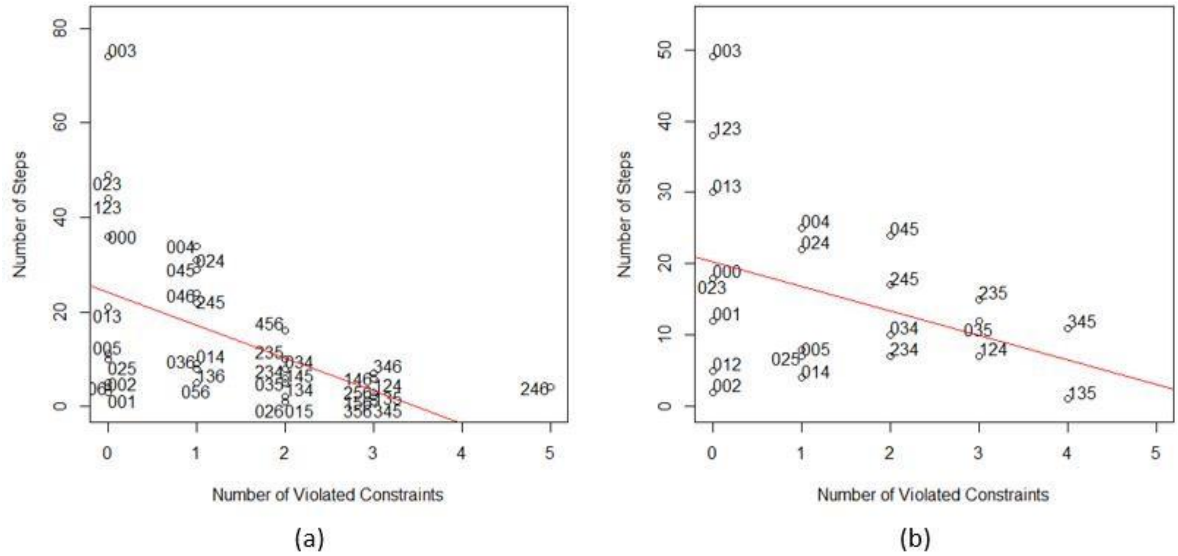

Figure 6. The correlation between the occurrence frequency and number of violated constraints.

Table 3: Correlation and Proportion Analysis between number of states and occurrence frequency in Level 5.

Assign-ment	**State and Occur-rence**	**Number of Violated Constraints**						**State vs Occurrence**	
		0	**1**	**2**	**3**	**4**	**5**	**Chi-Square**	**p**
1	State	0.24	0.19	0.14	0.19	0.19	0.05	< 0.01	**
	Occurrence	0.19	0.39**	0.23*	0.11	0.08+	0.01**		
2	State	0.29	0.21	0.24	0.21	0.00	0.05	< 0.01	**
	Occurrence	0.51	0.33	0.11	0.05	0.00	0.01		
3	State	0.31	0.19	0.19	0.23	0.08	0.00	0.136	ns
	Occurrence	0.50	0.19	0.17	0.10	0.04	0.00		
10	State	0.31	0.19	0.19	0.23	0.08	0.00	0.072	+
	Occurrence	0.40	0.26	0.15	0.16	0.03	0.00		
11	State	0.50	0.07	0.14	0.05	0.14	0.10	< 0.01	**
	Occurrence	0.91**	0.02*	0.05*	0.00**	0.01**	0.00**		
12	State	0.24	0.19	0.17	0.24	0.12	0.05	< 0.01	**
	Occurrence	0.42*	0.25	0.13	0.18	0.02**	0.01*		

**: significant difference (p<0.01), *: significant difference (p<0.05), +: marginal difference (p<0.1)

In addition, we pay attention to the proportion of occurrence frequency compared to number of states according to violated constraints. We found that the occurrence frequency in the high violated constraints is lower than the number of states, while the occurrence frequency in the low violated constraints is higher than the number of states. This implies learner were trying to avoid in making composition of sentence cards with high number of violated constraints. Moreover, we show the proportion for assignment 3 and assignment 10 which have no significant difference. Figure 7 shows the proportion of assignment 3, while Figure 8 shows the proportion of assignment 10. It can be seen that the proportion of occurrence frequency that is more than the number of states happens mostly at the zero and one violated constraints. It means that learners tried to arrange as little as possible the composition of sentence cards that could potentially have many violated constraints. This finding strengthen our assumption that many steps of learners had an inclination to avoid as many violated constraints as possible in arranging the intermediate products.

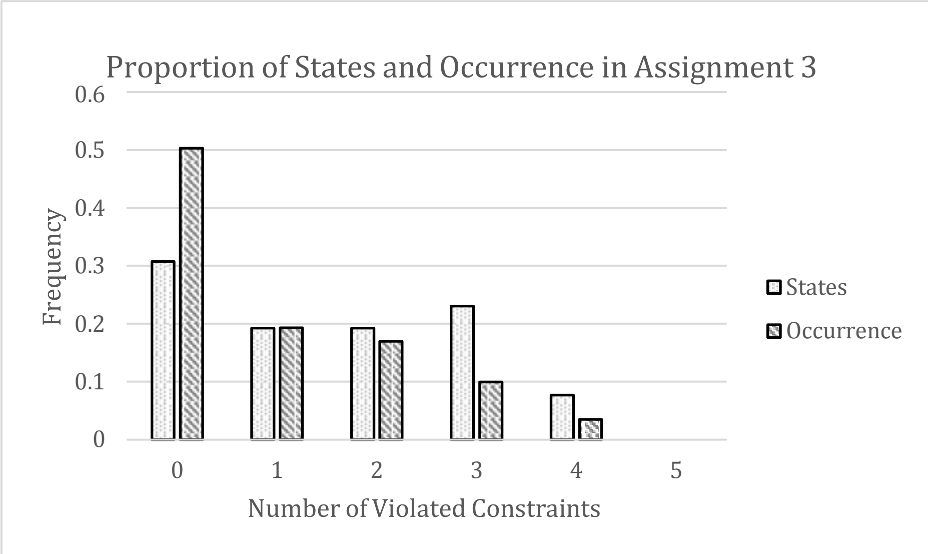

Figure 7. The proportion of the number of states and occurrence frequency in Level 5 Assignment 3.

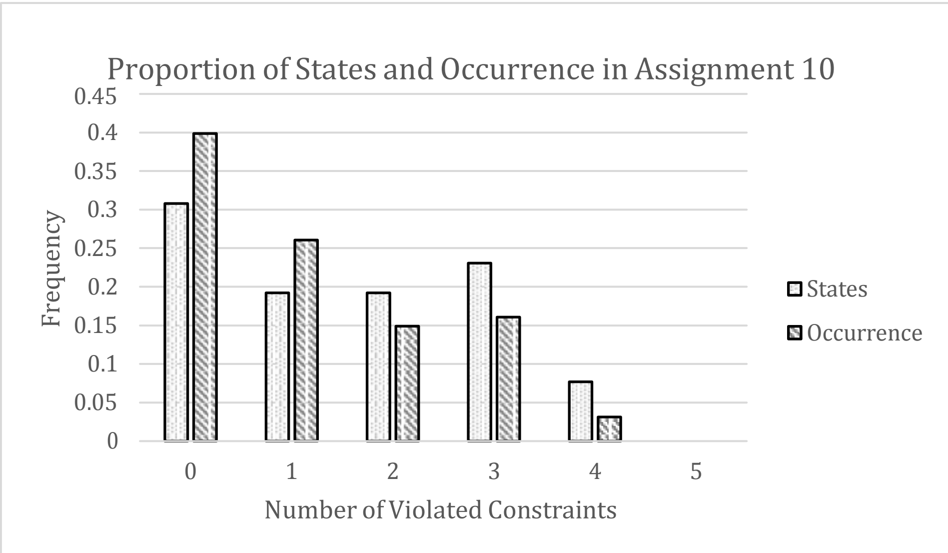

Figure 8. The proportion of the number of states and occurrence frequency in Level 5 Assignment 10.

4. Conclusion and Future Works

We conducted an analysis of intermediate products on the way to pose problems from MONSAKUN log data of elementary school students in problem-posing activity to investigate their way of thinking in posing of arithmetic word problems has been conducted. The analysis involves the intermediate products on the way to pose problem in order to prove that the learners attempt to avoid invalid intermediate products. Correlation between the numbers of violated constraints in the intermediate products and the frequency of each intermediate product which the learners actually made has reported. Significant difference in five out of six assignments is found, which shows that many steps performed by learners had an inclination to avoid as many violated constraints as possible. Further analysis to the assignment with no significant difference has conducted. The results strengthen our assumption that learners attempted to arrange as little as possible the composition of sentence cards that could potentially have many violated constraints.

For future research, we plan to analyze more detail about characteristics of learners' thinking process. Furthermore, we would like to use a data mining method, such as sequential data mining to discover learners’ action sequences on the way to pose the problems, and clustering method for grouping learners’ thinking process. We also would like to explore ways to identify the other significant actions. These are required to define learning support depending on each learner's cause of mistake and develop adaptive function for learning by problem-posing.

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