Markov Chain Analysis for Predicting Help Selection in Metacognitive Help-seeking

M Sumadyo, H B Santoso, D I Sensuse, R F Aji, A Hidayati, R Wahyuni

1Faculty of Engineering, Universitas Islam 45, Bekasi, Jawa Barat, Indonesia
2Faculty of Computer Science, Universitas Indonesia, Depok, Jawa Barat, Indonesia

E-mail: malikus.sumadyo@ui.ac.id

Abstract. One of the metacognition techniques is to provide help in solving items using help-seeking. This technique is important in improving metacognitive skills, because it contains an awareness of the need for help, monitoring knowledge and choosing a strategy to get the appropriate help and then evaluating the episode help. Metacognitive skills contain the dimension of metacognitive knowledge. Therefore help-seeking is arranged according to that dimension. However, the help-seeking series have not been able to measure whether the assistance is too excessive to meet the needs of students or even less fulfilling. This study simulates the needs of students for assistance with a help-seeking series arranged in the Markov Chain so that the assistance provided to students in a personal manner will be in accordance with the needs so that the process of finding assistance will be more efficient. The task is given to a number of students to complete the questions with hint steps in the help-seeking series. The Markov Chain are used to predict the tendency of the hint type selection to be resolved in a certain order. The results will help the education facilitator to monitor students in completing the items with the help of hints.

1. Introduction

In Educational Psychology, metacognition as one part of cognition defined as the ability of individuals to reflect, understand, and control their own cognition [1]. The ability is used to monitor various kinds of cognitive activities with actions and interactions between, a) metacognitive knowledge; b) metacognitive experiences; c) objectives or tasks that must be completed; and d) actions or strategies Flavel [2]. Whereas according to Moshman [3], metacognitive theory is a theory that integrates one's knowledge of cognition and cognitive settings. Even the ability of metacognition is more capable to solve problems than just using cognition, expressed by Flavel [4].

Metacognitive has two dimensions, metacognitive knowledge and metacognitive regulation. Metacognitive knowledge refers to one's cognitive process which consists of knowledge of personal variables, knowledge of task variables and knowledge of strategy variables, while metacognitive regulation refers to someone's procedural knowledge to regulate cognitive processes with four processes namely planning, monitoring, evaluating and revise [5].

Metacognitive is positively correlated with self-efficacy, whereas cognitive action is actually negatively correlated. The video analysis conducted by [6] revealed that there was a profile of cognitive action and metacognitive strategies that differed between high and low computer self-efficacy groups.

In the learning process, students need to ask for help from people who are more knowledgeable or other objects that provide assistance in facing academic difficulties [7]. This behavior is referred to as
help-seeking behavior which is part of an independent learning strategy. A student can determine when help is needed and how to receive that assistance [8] [9]. However, a student often does not use help facilities effectively, therefore according to [10], it requires metacognitive support to encourage learner help-seeking behavior in computer-based interactive learning. Thus, the help-seeking model is a model for effective help seeking behavior. This model uses estimation of mastery of knowledge to predict the most useful actions at each point of the learning process [11].

Help-seeking is defined as an act of seeking help to meet needs [12]. It is one of the techniques of metacognition in learning. This technique provides a step-by-step guide when students solve problems as well as learning problems and even practice solving complex problems. Some tutorial systems offer help in the form of on-demand contextual cues that give direction to how to solve problems [13].

Help-seeking is also defined as metacognitive skills [8] that influence learning in many situations and domains [13]. Apart from being a manifestation of self-regulation, help-seeking is also an important strategy that can be an instrument in developing independent skills and abilities. Empirically, help-seeking has been identified by [14] as an effective learning strategy and is related to the capacity for self-regulated learning.

In help-seeking, the facilitator will monitor the help search option [15]. Cognitive abilities that are monitored by students will increase awareness in planning item completion [15]. Help-seeking research was developed by Roll [13] as part of a tutor system to secretly assess students’ learning moments per moment.

Student errors in help-seeking can be obtained from the results of feedback which is a combination of learning instruction and self-assessment. The technique of measuring help-seeking behavior was discovered by Vaessen [16], through calculating frequency and sequentiality in choosing instructions for solving problems.

In the term of features, provision of help-seeking is sometimes not in accordance with the level of user metacognitive skills. For instance, users who are just at the stage of awareness of the need for help, were given direction using a strategy to obtain help. As a result metacognitive errors occur and help-seeking behavior becomes unproductive [17]. To reduce this error, it is necessary to predict the tendency of users on metacognitive abilities in searching for help.

In assessing a situation of help-seeking, there is often uncertainty, including assessing metacognitive skills. These problems can be modeled mathematically based on a regular pattern so that they can be expressed as a probabilistic model. One method that can be used in modeling these uncertain conditions is the Markov Chain. This paper examines the application of Markov Chains to predict the tendency of students as the users to determine their metacognitive abilities.

2. Related Work

In [17] it was revealed that in a help-seeking series, students with high abilities, were predicted to be needing one third of the available level hints, after asking the first hint. Meanwhile intermediate ability students need 2/3 and, low-ability students need all the hints. The help-seeking model was developed by Newman [17] with steps: (1) being aware of the need for help; (2) deciding to look for help; (3) identifying potential help; (4) using strategies to obtain help; (5) evaluating help-seeking episodes.

In the model it is explained that when students search for help, first begins by realizing that they need help such as assessing the difficulty of the item, monitoring the progress of understanding the item, or evaluating their ability. Next, they must consider all available knowledge or information and decide whether to look for help. This decision might involve several factors, such as the self-assessment of progress or skills, such as prestige, fear of shame, and reluctance to be helped. Next, students must find appropriate assistance. The choice of help may depend on the age and competence of the students, as well as the sensitivity of help. Then students must decide how to apply for help based on their knowledge and abilities. Finally, they must consider the help-seeking process to determine the next help.

Research that explores help-seeking behavior in web-based collaborative learning environments has been carried out by [9]. Framed as educational design research (EDR), three iterations have been
carried out in exploration. Through an iterative cycle of research, search tools are continually being improved, and the nature of online help search behavior is examined again. The results of this study reveal the principles of help search where help-seeking tools are built, and lead to the generation of new theories that explain online help-seeking behavior, and new design principles to support help-seeking.

Vaessen [16] defines the Markov model as a probabilistic model of a number of processes or activities with n states, transition probabilities and initial state probabilities. For instance, if the transition probability is 0.4 for the activity stage from X activity to Y activity, it can be interpreted that if a student does X activity, there is a possibility that 40% of the students will do Y activity.

This paper emphasizes on methods to predict the tendency of a student’s choice in solving learning problems. It is assumed that a student who seeks help is always inseparable from the type of assistance chosen. This resembles the principles of the Markov chain. Therefore the probabilistic approach with the Markov Chain becomes a tool for predicting the selection of the nth learning problem solving.

3. Method
The series of learning questions is assumed to be a process in the Markov chain, where each hint option in the help-seeking of item is assumed to be a state. In other word, item equals being in a particular process. Then if students choose one or more of the assistance provided for the item, then they have chosen one state. The next item will be assumed as well. In doing so, the item of n of the markov value from the hint type is selected. Thus the process to n + 1 can predict the greatest chance of students to choose the help-seeking type. A flowchart for predicting the probability of help status in the P process is illustrated in Figure 1,

![Flowchart](Image)

**Figure 1.** Transition Matrix Method Flowchart.

Markov Chain Analysis is a method that studies the properties of a variable in the present that is based on its characteristics in the past in an effort to assess the properties of these variables in the
future. It can be said that this analysis is a mathematical technique or probabilistic model to forecast changes in certain variables based on knowledge from previous changes. The basic concept of markov analysis is the state of the system or transition state. The nature of this process is that if the process is known to be in a certain situation, then the chance of developing the process in the future depends only on the current situation and does not depend on the previous situation. Hence, the Markov Chain is a series of events come depending on the current event.

Transition probability is a change from one state to another in the next process and is a random process expressed in probability. Thus based on the assumption above, the transition probability in solving the problem using the help-seeking sequence can be seen in Table 1 below, where \( n \) is the number of state hints in the process of solving each item, and \( p_{ij} \) is the possibility of transitioning from state \( i \) to state \( j \).

| From \( i \) state | To \( j \) state | \( 1 \) | \( 2 \) | ... | \( j \) | ... | \( n \) |
|-----------------|-----------------|------|------|-----|------|-----|------|
| \( 1 \)         | \( p_{11} \)    | \( p_{12} \) | ... | \( p_{1j} \) | ... | \( p_{1n} \) |
| \( 2 \)         | \( p_{21} \)    | \( p_{22} \) | ... | \( p_{2j} \) | ... | \( p_{2n} \) |
| ...             | ...             | ...   | ... | ...   | ...   | ...   |
| \( i \)         | \( p_{i1} \)    | \( p_{i2} \) | ... | \( p_{ij} \) | ... | \( p_{in} \) |
| ...             | ...             | ...   | ... | ...   | ...   | ...   |
| \( n \)         | \( p_{n1} \)    | \( p_{n2} \) | ... | \( p_{nj} \) | ... | \( p_{nn} \) |

Each \( p_{ij} \) is a non negative number and is not greater than 1, and the number of states for each process is 1, so that,

\[
0 < p_{ij} < 1 \quad \text{for } i = 1, 2, 3, ..., n \\
\sum_{j=1}^{n} p_{ij} = 1 \quad \text{for } j = 1, 2, 3, ..., n
\]

In help-seeking it is known that there are 5 states according to the stages developed by Newman in second section. The first is stage of awareness of the need for help, the second is stage of deciding to find help, the third is stage of identifying help potential, the fourth is stage of using help strategies, and the fifth stage is evaluating help-seeking episodes. The five states are tiered, meaning one state has to be completed before the next begins. However, in each process or in each settlement of the item, the state can return back to the initial stage, and may proceed to a completely different stage changes.

One thousand fictitious learners completed simulated learning questions with help-seeking series arranged according to Newman's stages. All students noticed the hint or help usage state during the first and second item completion process. Help 1 is a question about the awareness of students to ask for help. Help 2 is a guide to identifying students deciding to seek help. Help 3 is a guide that helps identify potential help. Help 4 is a guide to using strategies to get help. Help 5 is a guide to evaluating help-seeking episodes. The number of help users in process 1 is evenly distributed on each help status, which is 200 students in each status. Changes in the choice of stages in the first and second processes are tabulated in Table 2.

| State in Process 1 | State in Process 2 |
|-------------------|-------------------|
| \( 1 \)           | \( 2 \)           | \( 3 \) | \( 4 \) | \( 5 \) |
| \( 1 \)           | 40    | 80    | 40    | 30    | 10    |
| \( 2 \)           | 10    | 50    | 110   | 20    | 10    |
| \( 3 \)           | 2     | 20    | 40    | 100   | 39    |
| \( 4 \)           | 1     | 10    | 30    | 39    | 120   |
| \( 5 \)           | 1     | 2     | 30    | 40    | 127   |

So that the probability of changing help selection state from the first process to the next process meets the state transition table according to Table 3.
Table 3. Probability Transition State Tables.

| State in Process 1 | State in Process 2 |
|-------------------|-------------------|
| 1                 | 2 3 4 5           |
| 1                 | 0.2 0.4 0.2 0.15 0.05 |
| 2                 | 0.05 0.25 0.55 0.1 0.05 |
| 3                 | 0.01 0.1 0.2 0.5 0.19 |
| 4                 | 0.005 0.05 0.15 0.195 0.6 |
| 5                 | 0.005 0.01 0.15 0.2 0.635 |

Thus the probability matrix for changes (Transition Matrix) in the help stage or state selection in the first process to the second process is,

\[
\text{Transition Matrix} = \begin{bmatrix}
0.2 & 0.4 & 0.2 & 0.15 & 0.05 \\
0.05 & 0.25 & 0.55 & 0.1 & 0.05 \\
0.01 & 0.1 & 0.2 & 0.5 & 0.19 \\
0.005 & 0.05 & 0.15 & 0.195 & 0.6 \\
0.005 & 0.01 & 0.15 & 0.2 & 0.635
\end{bmatrix}
\] (1)

The matrix is used as the basis for determining the probability of changing state from process \( n \) to process \( n + 1 \), by multiplying the matrix \([1x5]\), which contains the probability of the first process on a certain state with a matrix \([5x5]\), which contains the probability of change. For instance, if students choose help 1 first in solving the problem, then the probability of the help option in solving the second problem is as follows:

If the choice in the first question process is help 1, then the probability is applied, \( P_1=1 \), \( P_2=0 \), \( P_3=0 \), \( P_4=0 \) and \( P_5=0 \). If probabilities are arranged in the form of row vectors then,

\[
\begin{bmatrix}
P(1)_{1} & P(1)_{2} & P(1)_{3} & P(1)_{4} & P(1)_{5}
\end{bmatrix} = \begin{bmatrix}1 & 0 & 0 & 0 & 0\end{bmatrix}
\] (2)

The formula for determining the probabilities of the next process is,

\[
\begin{bmatrix}
P(n+1)_{1} & P(n+1)_{2} & P(n+1)_{3} & P(n+1)_{4} & P(n+1)_{5}
\end{bmatrix} = \begin{bmatrix}
P(n)_{1} & P(n)_{2} & P(n)_{3} & P(n)_{4} & P(n)_{5}
\end{bmatrix} \times \text{Transition Matrix}
\] (3)

Thus that for the process of solving the second problem, the probability is obtained,

\[
\begin{bmatrix}
P(2)_{1} & P(2)_{2} & P(2)_{3} & P(2)_{4} & P(2)_{5}
\end{bmatrix} = \begin{bmatrix}1 & 0 & 0 & 0 & 0\end{bmatrix} \times \begin{bmatrix}0.7 & 0.4 & 0.7 & 0.15 & 0.05 \\
0.05 & 0.25 & 0.55 & 0.15 & 0.05 \\
0.01 & 0.1 & 0.7 & 0.5 & 0.19 \\
0.005 & 0.05 & 0.15 & 0.135 & 0.6 \\
0.005 & 0.01 & 0.15 & 0.2 & 0.635
\end{bmatrix}
\] (4)

The result of multiplication of row vector and transition matrix is

\[
\begin{bmatrix}
P(2)_{1} & P(2)_{2} & P(2)_{3} & P(2)_{4} & P(2)_{5}
\end{bmatrix} = \begin{bmatrix}0.2 & 0.4 & 0.2 & 0.15 & 0.05\end{bmatrix}
\] (5)

Likewise for the next processes would produce many of following matrices

\[
\begin{bmatrix}
P(3)_{1} & P(3)_{2} & P(3)_{3} & P(3)_{4} & P(3)_{5}\end{bmatrix} = \begin{bmatrix}0.63 & 0.208 & 0.33 & 0.20925 & 0.18975\end{bmatrix}
\] (6)

\[
\begin{bmatrix}
P(4)_{1} & P(4)_{2} & P(4)_{3} & P(4)_{4} & P(4)_{5}\end{bmatrix} = \begin{bmatrix}0.283 & 0.12256 & 0.25285 & 0.274 & 0.32229\end{bmatrix}
\] (7)

\[
\begin{bmatrix}
P(5)_{1} & P(5)_{2} & P(5)_{3} & P(5)_{4} & P(5)_{5}\end{bmatrix} = \begin{bmatrix}0.1073 & 0.08417 & 0.21308 & 0.26081 & 0.42404\end{bmatrix}
\] (8)
At five decimal place accuracy, the process would experience stability or no change in $P_{18}$,

$$
[P_{(18)1} \ P_{(18)2} \ P_{(18)3} \ P_{(18)4} \ P_{(18)5}] = [0.01029 \ 0.05284 \ 0.18069 \ 0.24717 \ 0.50901] \ (9)
$$

Thus, if help 1 chosen in the process 1, then the 18th process and so on would have the option to choose help 1 is 2 learners, help 2 is 11 learners, help 3 is 36 learners, help 4 is 49 learners and help 5 is 102 learners.

If the choice in the first question process is help 2, then the probability is applied, $P_1=0$, $P_2=1$, $P_3=0$, $P_4=0$ and $P_5=0$. Below are the probabilities arranged in the form of row vectors,

$$
[P (1)1 \ P(1)2 \ P(1)3 \ P(1)4 \ P(1)5] = \begin{bmatrix}
0.2 & 0.4 & 0.2 & 0.15 & 0.05 \\
0.05 & 0.25 & 0.55 & 0.15 & 0.05 \\
0.05 & 0.05 & 0.15 & 0.195 & 0.8 \\
0.05 & 0.01 & 0.15 & 0.2 & 0.635
\end{bmatrix} \times
\begin{bmatrix}
0 \\
1 \\
0 \\
0 \\
0
\end{bmatrix} \ (10)
$$

Thus that for the process of solving the second problem, the probability is obtained,

$$
[P (2)1 P(2)2 P(2)3 P(2)4 P(2)5] = [0.05 \ 0.25 \ 0.55 \ 0.01 \ 0.05] \ (11)
$$

The result of multiplication of row vector and transition matrix is

$$
[P (2)1 P(2)2 P(2)3 P(2)4 P(2)5] = [0.2875 \ 0.143 \ 0.28 \ 0.337 \ 0.21125] \ (12)
$$

Likewise for the next processes would produce many of following matrices,

$$
[P (3)1 P(3)2 P(3)3 P(3)4 P(3)5] = [0.01844 \ 0.09421 \ 0.22264 \ 0.26658 \ 0.39813] \ (13)
$$

$$
[P (4)1 P(4)2 P(4)3 P(4)4 P(4)5] = [0.1395 \ 0.0705 \ 0.19974 \ 0.25512 \ 0.46069] \ (14)
$$

At five decimal place accuracy, the process would experience stability or no change in $P_{17}$ as follows,

$$
[P (17)1 P(17)2 P(17)3 P(17)4 P(17)5] = [0.01029 \ 0.05284 \ 0.18069 \ 0.24717 \ 0.50901] \ (16)
$$

Thus if help 2 is chosen in the process 1, then the 17th process and so on will have the option to choose help 1 is 2 learner, help 2 is 11 learner, help 3 is 36 learner, help 4 is 49 learner and help 5 is 102 learner.

All choices in the first process have a stable probability with a value of $[0.01029 \ 0.05284 \ 0.18069 \ 0.24717 \ 0.50901]$ in different $n^{th}$ process, Table 4 is a process of stable probability in each first choice,

| First Process | Cessation of change |
|---------------|---------------------|
| Help 1        | $n = 18$            |
| Help 2        | $n = 17$            |
| Help 3        | $n = 15$            |
| Help 4        | $n = 16$            |
| Help 5        | $n = 17$            |
4. Results and Discussion

In the simulation performed in section 3, it could be stated that if a student in the first problem solving process chooses help option 1, it is more likely to increase the probability of help 2 to be chosen in the second process. Similarity in the third process, it is more likely to increase his/her likelihood in choosing help 3; choosing help 4 in the 4th process, and the option help 5 in 5th process. It means, each student tended to have an increase of help-seeking use skill in each process of solving problems with the help-seeking metacognitive level according to the current stage. However, it also turned out that not all students had an increasing process. There were always students who returned to help 1 even though the probability was getting smaller.

The results illustrate that a student has a tendency to always have an increase in his/her metacognitive abilities to get help-seeking and reevaluate what he/she has gotten in help-seeking.

Figure 2. First Process = Help 1.

Figure 3. First Process = Help 2.
The nature of improvement tends to be gradual from stage 1 in the term of awareness of their need for assistance after feeling inadequate in solving learning problems. In the next stage, student inclined to seek for help. This stage is followed by the ability to identify potential assistance a guidance. Having enough understanding of potential assistance would encourage students to strategize their way to obtain the most effective assistance. From this stage, students would evaluate each episode of help so that the help-seeking process becomes a more effective effort to solve learning questions.

![Figure 4. First Process = Help 3.](image)

The choices in the first process might have different tendencies, but would overlap at some point. All of these choices have a convergence point at the 17th process. Figure 2, 3, 4, 5 and 6 show the tendency of each choice at a certain point even though it starts from a different help choice.

![Figure 5. First Process = Help 4.](image)
From these trends it could be concluded that students’ metacognitive level would reach a stagnant point at the completion of item 17. Thus, in order to increase the level of help-seeking metacognitive levels, it is suggested to make a question more than 17 items. Thus the benefits of using the Markov Chain in this help-seeking, is not only predicting the tendency of students to make help choices but also to predict help-seeking metacognitive abilities when completing a number of items. The facilitator can recommend the minimum number of items to be arranged to practice metacognitive abilities.

5. Conclusion
In help-seeking student have a tendency to increase effectiveness in solving items. Metacognitive abilities in help-seeking will always compare and evaluate the knowledge it already has, with the items about learning and help provided. The process of awareness of the need for help begins when there is an inability to solve the items. Thus, help is the best way to solve it. Their decision to seek help was the next stage which was driven by that awareness. The next stage is in accordance with the stages compiled by Newman.

Markov chains are simple and effective methods for predicting the probability of a choice of help-seeking stages. The transition matrix in this method becomes very dominant in determining the probability value in the nth process and the numbers in the matrix greatly influence the results of the analysis of students’ tendency in selecting help-seeking stages. However, this method is still its infancy to get an effective help-seeking process.

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