

Identifying Bottlenecks in Student Learning using Eye Tracking Measurements in Lathe Operation Training*

M. Kimizuka, Y. Ito, H. Saito, D. Chugo, and H.Hashimoto, *Member, IEEE*

Abstract— This paper aims to identify bottlenecks in learning lathe operation and find ways to reduce the workload of the identification, in order to analyze effective and efficient learning processes for lathe operation training for beginner students. This paper considers bottlenecks suitable for practical training and proposes a method for measuring bottlenecks using an eye tracker to reduce the workload required for identification. Based on this method, bottlenecks during student training are identified and discussed.

I. INTRODUCTION

This paper aims to identify bottlenecks in learning during lathe operation training and reduce the workload of the identification in order to understand effective and efficient learning processes for beginner students.

This machining must be completed within a specified time. As the material is gradually processed, visual inspection and manual work are required to confirm its shape and machining accuracy, and auditory perception is also necessary to evaluate the machining sounds during the process. In other words, acquiring these perceptual skills is also required in this practical training. To understand the accuracy and precision involved, prior knowledge of metal properties, machining operation methods, and machining standards and precision is also necessary.

From this, we can see that the main learning elements of this training are physical movements for operating equipment, perception during material processing, and knowledge of processing, and that it requires the integration of movement, perception, and knowledge. Since knowledge is learned before the training, the training focuses mainly on the integration of movement and perception, so it can be considered as learning for the integration of movement and perception. Until now, the quantitative evaluation of this integration has been difficult, so resolving this issue has been desired in order to significantly improve the effectiveness of learning evaluation and instructional design.

Understanding the state in which this integration is gradually formed is one of the most important challenges in measuring the degree of learning, but because this state involves psychology and perception, direct measurement is extremely difficult. For this reason, there are studies that use simulators and VR rather than directly measuring learners

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M. Kimizuka, Y. Ito, and H. Saito are with the Mechanical Systems Engineering Course, Tokyo Metropolitan College of Industrial Technology, Tokyo, Japan (e-mail: {m.kimizuka,y-ito,saito.h}@metro-cit.ac.jp).

D. Chugo is with the School of Science and Technology, Kwansai Gakuin University, Hyogo, Japan (e-mail:chugo@kwansei.ac.jp).

H. Hashimoto is with the Advanced Institute of Industrial Technology, Tokyo, Japan (corresponding author, e-mail:hashimoto@aait.ac.jp).

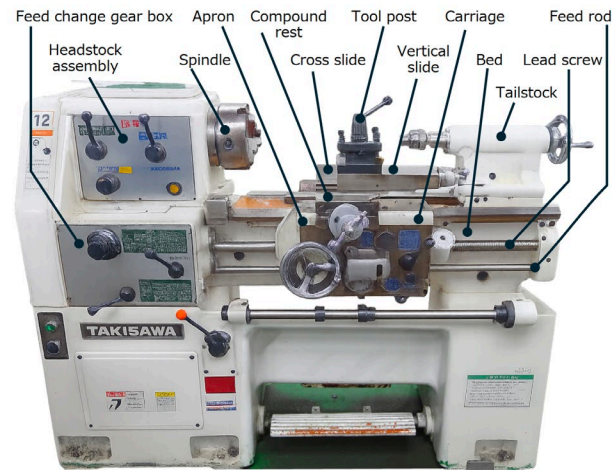


Figure 1. Diagram of lathe machine.

[1-2]. While this research is effective in understanding the norms of operation and changing processing states, it does not take into account individual characteristics, and therefore does not discuss learning that is appropriate for each individual.

In order to effectively design learning programs, it is useful to identify bottlenecks in the learning process. Several studies have previously explored the attributes of bottlenecks that hinder learning [3-6]. In these studies, bottlenecks are classified into multiple attributes. These classifications primarily include superficial ones, such as procedures and learning time; internal ones, such as confusion due to insufficient deep understanding, cognition, or perception; and personal beliefs, such as the learner's own beliefs. Furthermore, conventional bottleneck identification relies solely on the instructor's observation, and since this task is enormous, it is also important to consider ways to reduce it.

The authors have been conducting research into the digitalization of lathe operation training [7-8]. Through this research, we have shown that the skill level of operation is related to the operator's line of sight. Furthermore, humans sometimes operate devices without looking at them. We have found that when the line of sight and operation do not match, there are distinctive differences between experts and beginners. Based on these findings, we have come up with the idea of defining the attributes of bottlenecks suitable for lathe operation training.

Based on these ideas, this study proposes attributes of bottlenecks that are appropriate for movements and perceptions in practical training. Taking this into consideration, we introduce eye-tracking as a measurement method. The eye-tracking can measure gaze distribution and the time it

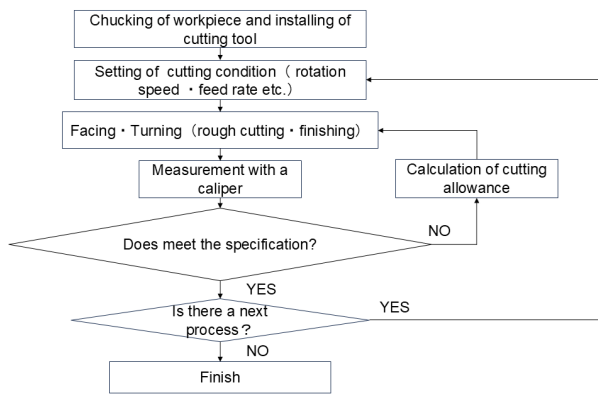


Figure 2. Practical training flowchart.

takes to form that distribution, which is useful for quantitatively expressing the bottlenecks under consideration.

Furthermore, since it is lightweight and can correct for the effects of head movement using a gyroscope, it facilitates measurements during work and reduces the amount of work required to identify bottlenecks. Using the proposed measurement method, measurements were taken of some students and two model instructors, and quantitative expressions of bottlenecks are presented. From this, bottlenecks that occur in beginners are discussed.

II. LATHE OPERATION TRAINING PROCESS

In lathe operation training, students operate the lathe shown in Fig.1. The lathe has several kinds of control devices (levers, handles, etc.) located in various positions, and these controls are used to adjust the position of metal materials and cutting tools, control rotation speed, and perform other operations.

First, the tool installation, such as chucking of the workpiece and installing of cutting tool, is performed before the lathe operation. This involves installing tools (such as cutting tools) on the tool-post and tailstock, installing the material to be processed on the spindle, and mastering these procedures. During this process, the installation time and accuracy must meet specified standards..

When operating a lathe, students focus their gaze on the distributed operating devices, place their face or body in that direction, perform the machining operation with their hands, and perceive the condition during machining. They then occasionally stop operation to measure the machining accuracy of the material with a caliper and check whether it meets the given specifications. As shown in Fig.2, which is a flowchart of the above process, students learn lathe operation by repeating the loop until the machining accuracy meets the specified standards, i.e., satisfies the specifications, within the allotted time. This is confirmed in the decision block, whether all of the shapes of the material to be processed meet the given accuracy or not.

Rough cutting is the first process in the machining process, where the material is roughly removed to shorten the work time. This process does not meet the specifications, so the first decision block in the flowchart always returns NO.

Finishing is the process of fine machining in subsequent stages to achieve the desired accuracy. In the first judgment block, the finishing accuracy is measured, and a judgment is made as to whether or not it meets the specifications.

Table I shows the rotation speed and feed rate for lathe cutting. The feed rate and depth of cut differ depending on whether it is rough machining or finish machining, and this not only directly affects the work time but is also thought to have a large impact on perception, so we will consider this later as a factor in which process a bottleneck occurs.

TABLE I. LATHE OPERATING SETTINGS

Type of processing	Rotation speed (rpm)	Feed rate (mm/rev)	Cutting depth per pass (mm)
Outer diameter (rough cutting)	560	4	1.0
Outer diameter (finishing)	1030	0.1	max 0.2
Boring (rough cutting)	560	0.2	1
Boring (finishing)	1030	0.1	max 0.2

The bottlenecks that can be expected during processing are as follows: the time required for spatial physical movement and visual confirmation of the processing status and shape measurement for each operation shown in Figure[flowchart], as well as the imbalance in integration required to simultaneously perceive the processing status of the material (visual perception of the processing surface, auditory perception of processing sounds, etc.) while recognizing multiple positions.

III. SETTING AND MEASURING BOTTLENECKS

A. Setting Bottlenecks

The objective of lathe operation training is to acquire the skills necessary to perform machining that meets specified requirements for metal materials within a given time frame. Lathe operation consists of multiple processes, as shown in Chapter 2, and each process requires multiple steps. Each step requires the integration of various physical movements and perceptions for accurate and quick lathe operation.

Meanwhile, bottlenecks in learning theory have been the subject of numerous studies because they are an important issue in the smooth and effective design of learning programs. Previous studies [9-11] have broadly categorized bottlenecks into procedural, cognitive, and emotional bottlenecks. Considering that the lathe operation training involves multiple processes and promotes sensory-motor integration, we adopted the first and second bottlenecks. The third bottleneck is excluded as it is based on the learner's beliefs and religious beliefs and is therefore inappropriate for this training.

- BN1: Procedural Bottlenecks
- BN2: Cognitive Bottlenecks

The original meaning of BN1 is the specific process within a series of processes that slows down the overall progress the most. In lathe operation, each process involves multiple steps, such as turning the handle, removing and attaching the material, and measuring the installation accuracy and machining status, and it is considered important to know in which step the

bottleneck occurs. To measure procedural bottlenecks, operation time is measured, as short operation times are required. However, it is expected that operation time will vary from person to person. For this reason, as another indicator of BN1, the number of times a caliper is used for precision checks, as specified in the specifications, is also taken into consideration.

The original meaning of BN2 refers to a situation in which an evaluation requires multiple perceptions, but that evaluation is insufficient due to the lack of a certain perception (often based on perception, knowledge, or skill). This is in contrast to when one is confident, and some kind of difference is expressed as biological information. One of the objectives of this study is to identify this difference. If a certain skill cannot be utilized, high-quality processing cannot be achieved. When a skill has not been mastered, learners will experience processing states and results that they did not expect, which can often lead to negative emotions and upset. It is known that when this happens, the distribution of gaze becomes irregular as the learner attempts to grasp the entire situation [12-14]. Based on this, by measuring gaze, the absence of certain techniques or a lack of confidence can appear as the distribution pattern of the gaze. The results of analyzing this information are denoted as BN2.

B. Measurement method using an eye tracker

In this study, we used an eye tracker (Eye Tracking Core+) [15] to achieve both ease of measurement and a low burden on learners (Fig.3).

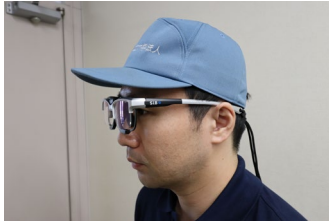


Figure 3. A learner wearing eye trackers.

As shown in the specifications in Table II, the lightweight and flexible eyeglass frame reduces the burden on learners when wearing the glasses. Furthermore, the gyro sensor allows for calibrated gaze measurement that takes head movement into account.

TABLE II. SPECIFICATION OF EYE TRACKER (EYE TRACKING CORE+)

Main unit size	177mm x 158mm x 28mm
Weight (glasses)	39.6 g
Weight (recording unit + controller)	168 g
Detection Rate (Binocular)	30Hz / 60Hz / 90Hz / 120Hz
Detection Method	Pupillary-Corneal Reflex Method / Pupil Method
Gaze Point Accuracy	0.5°
Gyro	built-in

The application (SiB Core Studio) for this eye tracker makes measurement easy. This application allows you to predefine multiple objects to be gazed at during operation and

calculate the distribution of gaze points per unit time for those objects. Therefore, if the object is stationary, the distribution appears to be within a fixed space. On the other hand, when the object slides or moves, the distribution is measured from the center of the object. When this is graphed, it appears to be in a certain subspace, but please note that it moves along with the object during measurement.

When determining this distribution, the duration of gaze is taken into consideration. This application can automatically measure gaze duration. The number of gazes is also a factor that can represent a person's psychology while working, and can be approximately calculated from the distribution recorded by the eye tracker. These measurement results are used in BN1 and BN2.

IV. EXPERIMENT

A. Skill level

This section describes the skill level of the student subjects. The subjects are five students, S_i ($i = a, b, c, d, e$), all of whom have a skill level below that of the beginner level. The learning goal is for students to acquire skills sufficient to reach the beginner level. In order to evaluate the skill levels of the students, the lathe operation of two instructors, T_j ($j = a, b$), will be used as a standard. Here, T_a is an intermediate skill level, and T_b is an advanced skill level. Here the skill levels of S_i and T_j are defined by JAVAD standard [16].

As an indicator of the attainment of the beginner's skill level, specifications for machining are given, and two metal materials are machined to meet these specifications. As mentioned in Chapter 2, machining work is repeated until the machining accuracy is achieved within the specified time, so the skill level evaluation here is not based on machining accuracy, but on the work time and actions taken during the work.

B. Measuring BN1

Perform the lathe practice described in Chapter 2 and determine the appropriate measurement values for BN1. Looking at the lathe practice time in Table III, we can see that the time required for S_i is approximately longer than that for T_j .

TABLE III. LATHE PRACTICE TIME

Students	Sa	Sb	Sc	Sd	Se
Working time (min)	81.5	70.5	66.4	73.3	58.7

Instructors	Ta	Tb
Working time (min)	63.6	39

The working time shown in Table III represents the total processing time until the precision of the finished dimensions meets the specifications, as shown in Fig.2. Therefore, it can be considered as an element of BN1. However, depending on the individual, there are cases where the finishing precision is pursued and time is spent on careful processing, so simply

comparing the time does not allow for a determination of whether or not there is a bottleneck.

In order to find out which process takes the most time, i.e., which process is the bottleneck, the proportion of work time for each subject is shown in Fig.4.

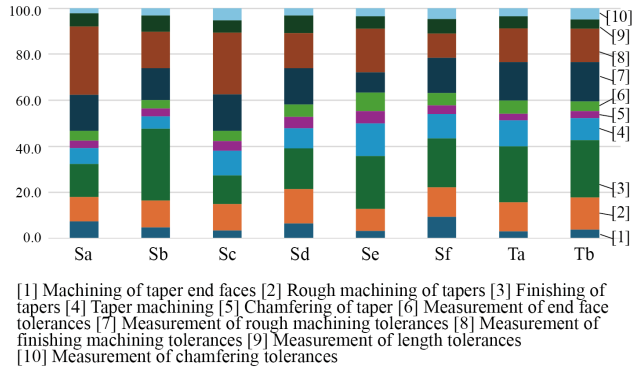


Figure 4. Proportion of work time.

As shown in Fig.4, we can see that in some parts of Si, the proportion of time required for rough machining is long. Reducing the time required for rough machining requires a high level of confidence, where the operation, perception, and predicted machining results match, and this can be thought of as a bottleneck for beginners who do not have enough of this match. We can also see that in some parts of Si, the proportion of time required for finishing machining is long. Finish machining requires caliper measurements during machining. Due to the lack of skill in this measurement and the need to ensure accuracy, there is a tendency to be more careful in making these measurements, which can be said to be a tendency for this measurement time to be long. This can be thought of as a bottleneck.

On the other hand, in the case of Tj, even though the cutting speed is slow (Table I), the proportion of time required for rough cutting is small. In other words, this is thought to be due to the operator's bold operation and the ability to predict the results of the resulting rough cutting, and the skill to derive those results. There were no significant differences in the proportion of work time for other processes between Si.

Based on the above considerations and the instructor's observations, we believe that the measurements using calipers during both processes are also a factor in BN1. Therefore, we measured the number of times the caliper was used and the gaze time during this time until completion in Fig.2, and the results are shown in Table IV. In the table, the average gaze time is a simple average obtained by dividing the gaze time by the total number of times it was used.

Looking at the table and comparing the number of times that calipers were used between Si and Tj, Si's was generally greater, with a difference of up to two times. Furthermore, the shorter the work time (Table III), the fewer the total number of times it was used, and the longer the average gaze time. According to the instructor's observations of this Si, it was found that all the necessary accuracy was measured with a single caliper measurement. On the other hand, Si, who had a relatively long work time, performed inconsistent caliper measurements and did not take each measurement carefully,

which meant that remeasurements were often required, increasing the number of times the calipers were used. It was found that these unnecessary measurements were leading to time losses.

TABLE IV. CALIPER USAGE COUNT

	Total number of uses	Viewing time [s]	Average viewing time [s]
Sa	24	164	6.83
Sb	19	161	8.47
Sc	28	152	5.43
Sd	15	96	6.40
Se	12	140	11.67
Ta	13	109	8.38
Tb	13	122	9.38

Based on the above, including the instructor's observations, it is considered appropriate to express BN1 using the measured values in Tables III and IV.

C. Measuring BN2

The heat map of gaze points during the entire lathe operation is shown in Fig.5. Here, based on the characteristics of the experiment, 16 objects were selected as gaze targets.

Comparing the gaze distribution (gaze distribution) of gazed objects for Si and Tj, Si's distribution is wider, meaning there is greater variability in gaze movements. This tendency is seen when people lack confidence. This is a tendency seen when people lack confidence. For example, they may look around at other places instead of focusing on the area they should be looking at. This is not only reflected in the spread of the distribution, but also leads to a dispersion of the gaze time. This dispersion can be seen by comparing with an expert. Thus, we will next consider the results of Tj.

Tj's gaze distribution was relatively high on the workpiece, and relatively low on the control objects (steering wheels, etc.) and the display panel. This is thought to be because Tj's spatial recognition ability for these objects is higher [17-18], and so he is able to operate the control objects, whose positions are known, with less eye movement. This suggests that he is able to concentrate on the workpiece, has less variance in his eye movements, and operates with confidence.

As analyzing the frequency of gaze distribution, we focused on the bottleneck of finishing machining, as pointed out in the previous section, and investigated the gaze distribution at this time. Fig.6, which is obtained from Fig.5, shows the gaze distribution percentage for taper side finishing machining.

It can be seen in Fig.6 that the shorter the Tj and the shorter the working time Si, the more the gaze is focused on the workpiece, tool post, and tool feed, and the less the gaze distribution on the caliper and drawings. Conversely, the longer the working time Si, the more the opposite situation is seen. This is thought to be because the worker is not confident that his or her own operations are achieving the required precision in the finish, so he or she checks the dimensions on the drawing, then checks them with the caliper, and there is no

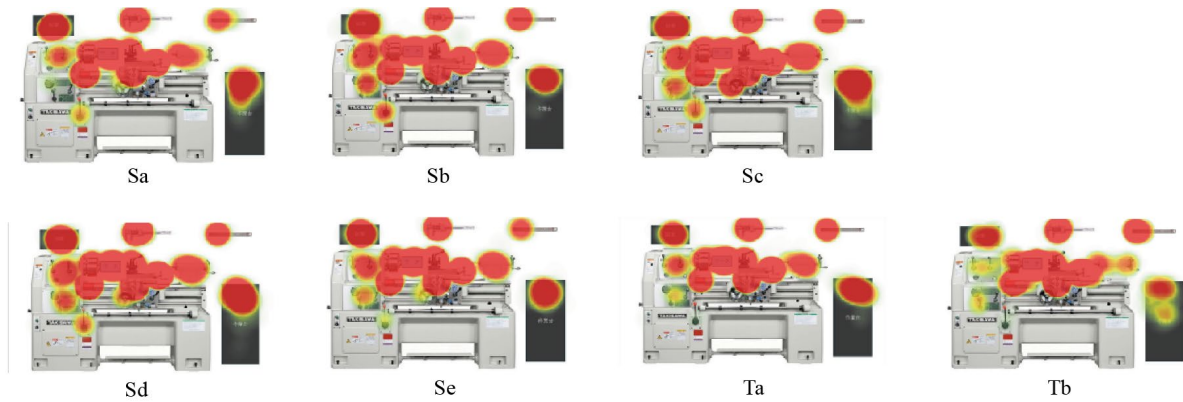


Figure 5. Heat map of gaze points during the entire lathe operation.

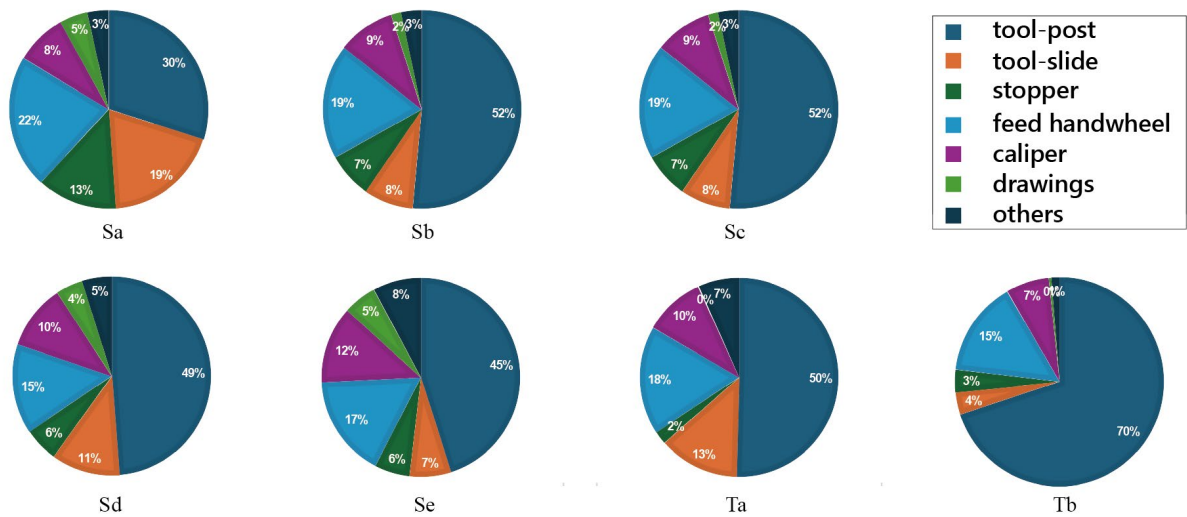


Figure 6. Percentage of attention distribution in taper finishing.

match between the operation of machining, knowledge, and perception, which leads to an increase in such unnecessary movements.

It can also be found that the proportion of gazes on the stopper (Fig.5) during finishing machining is low, and that automatic feeding is performed while the operator is looking at the workpiece. This is thought to be due to the same factors as mentioned above.

From the above, it can be said that for BN2, in order to see the integration of operation, knowledge, and perception, it is appropriate to look at Figs.5 and 6.

D. Discussion

In this practical training, the minor loop shown in the flowchart (Fig.2) is repeated until the required precision is achieved, and it is sufficient if this is completed within a specified time.

During machining operations, learners are required to concentrate on machine operation and observing the machining status of the workpiece. However, beginners were found to sometimes look around unnecessarily. By comparing this behavior to that of skilled instructors, this characteristic is considered a strong indicator of lower skill levels.

Sa, Sb, and Sc were shown to differ from those of Tj in terms of the proportion of working time (Fig.4), the number of caliper measurements (Table IV), and the variability in eye movement (Fig.5). Even through direct observation by the instructor, the operations were not particularly smooth, and it can be said that the bottlenecks mentioned in BN1 and BN2 exist. Therefore, it can be said that some form of guidance will be necessary when they proceed to the next higher level of training.

By contrast, Sd and Se achieved smooth operation and relatively high processing accuracy, even when observed by their instructors. Although Sd's work time was relatively long, it was within the specified time limit, and he showed an attitude of performing his work carefully. Therefore, there were no major bottlenecks for these two students, and it is believed that they will be able to smoothly proceed to the next higher level of training.

As explained above, this determination is performed almost automatically, except for visually measuring the number of times the caliper is used, which reduces the amount of work involved in identifying bottlenecks. Furthermore, because it is expressed quantitatively, it can be visualized, making it an indicator that is easy for instructors to use for learning evaluation and instruction design.

V. CONCLUSION

This paper defined two novel bottleneck attributes BN1 and BN2, which are suitable for lathe operation training, and attempted to reduce the burden of this identification work.

In order to improve on previous qualitative expressions and assessments based on the instructor's subjective observation, the BN1 and BN2 proposed in this paper are objective, quantitative expressions, and by using an eye tracker, have the advantage of significantly reducing the burden of bottleneck identification work. Furthermore, this method has the advantage of being able to take into account individual characteristics by taking into account the number of times the caliper is used visually.

Through the examination of the test subject's data, it was found that beginners lack the ability to match their operation and perception with the expected machining results, so they are unable to achieve the best results in rough machining, and the work takes a relatively long time. Also, in finish machining, they are too concerned about machining accuracy and spend a lot of time measuring with vernier calipers, and these are suitable elements for BN1.

In addition, as elements of BN2 related to human psychology, it was determined that the heat map of gaze points throughout the entire time of lathe operation, which roughly represents the psychology of expressing confidence, and the proportion of gaze point distribution, which provides clues to identify which process is being performed, are suitable.

By using these, we have demonstrated the possibility of quantitatively distinguishing between students with many bottlenecks and those with few. These evaluations of the selection of elements in BN1 and BN2 are also compatible with evaluations based on instructors' direct observations, and we believe they are effective indicators for learning evaluation and instructional design.

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