This paper proposes a learning goal space that visualizes the distribution of the obtained solutions to support the exploration of the learning goals for a learner. Subsequently, we examine the method for assisting a learner to present the novelty of the obtained solution. We conduct a learning experiment using a continuous learning task to identify various solutions. To assign the subjects space to explore the learning goals, several parameters related to the success of the task are not instructed to the subjects. In the comparative experiment, three types of learning feedbacks provided to the subjects are compared. These are presenting the learning goal space with obtained solutions mapped on it, directly presenting the novelty of the obtained solutions mapped on it, and presenting some value that is slightly related to the obtained solution. In the experiments, the subjects to whom the learning goal space or novelty of the obtained solution is shown, continue to identify solutions according to their learning goals until the final stage in the experiment is attained. Therefore, in a continuous learning task, our supporting method of directly or indirectly presenting the novelty of the obtained solution through the learning goal space is effective.

Keywords: learning support system, sub-reward, continuous learning, learning goal space, creative learning

1. Introduction

The progress of information technology will lead to the replacement of approximately half of the jobs performed by humans with computers in the near future. The remaining jobs that are of technical difficulty for both artificial intelligence and computers require high creativity or social skills. This paper describes the creativity of both humans and the computer system. According to Boden [1], “creativity is the ability to come up with ideas or artifacts that are novel and valuable.” Previous research on human creativity suggests that “one process of creating ideas involves making unfamiliar combinations of familiar ideas, requiring a rich store of knowledge” (Frey, C. B., 2015, p.26) [2]. However, it is extremely difficult for a computer to acquire the creativity of a human. This is so because it is unclear how to combine familiar concepts via unfamiliar approaches.

To solve this problem, we focus on a method to utilize the higher creativity of humans compared with that of computers. We propose a mechanism based on a framework of a continuous learning support system provided for a human learner to perceive creativity based on his/her own learning. In the proposed mechanism, the support system generates an already derived learning achievement by combining the original achievement with the solution determined by the learner. Consequently, the learner can reflect his/her own learning trace in the learning goal space. Based on the learning trace, the support system makes the learner aware of the unclear learning results and sense of values.

We propose three types of support methods. The first type is the visualization of the learning traces to support the discernment of creativity on learning. We design a learning goal space to visualize a learning trace. It is the distribution of the learning goals attained by a learner who learns an original achievement and of the derived goals generated by the support system. This makes it easier to reflect the learning orientation by showing the position of the learning goal relative to the learning trace.

The second type is a discovery support for obtaining unknown solutions by generating a derived achievement based on the negation of the shortest solution of the learner. This encourages the learner to identify his/her unclear solutions. The third type is the generation of a derived achievement by justification of the determined redundant solution. This encourages the learner to notice his/her unclear sense of values.

Supporting the Exploration of the Learning Goals for a Continuous Learner Toward Creative Learning


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2. Background

This section first presents the theoretical background of this research. Following this, we provide an overview of continuous learning because it is the basic framework of a creative learning process. Subsequently, we discuss what a creative learning skill is.

2.1. Definition of Continuous Learning

The concept of continuous learning comes from industrial and organizational psychology. Some industrial and organizational psychologists have attempted to conceptualize this term. Smita and Trey [3] in their review of the research on continuous learning classify it into three levels, namely, individual, group, and organizational levels. One of the conceptual definitions of continuous learning is as follows: “Continuous learning at the individual level is regularly changing behavior based on a deepening and broadening of one’s skills, knowledge, and worldview.” Our previous research on continuous learning is described in detail in [4] and [5].

2.2. Research on Creativity

We consider creativity at the base of the approach of Guilford [6]. According to Guilford (1987) [6], creativity displays the primary characteristics of sensitivity to problems, fluency in generating ideas, flexibility and novelty of ideas, and the ability to synthesize and reorganize information [7]. Sensibility to problems is the skill that leads to the identification of a problem. We consider that this is the skill required to comprehend a learning task. Fluency in generating ideas is indicative of the number of ideas a human can formulate. Flexibility is the skill to create various ideas. Novelty of ideas is the skill to formulate unusual concepts. The ability to synthesize and reorganize information is the skill to utilize an object for divergent purposes. We consider the skill requires focusing on the interpretation of the meta-learning process. Therefore, we describe several characteristics that are concerned with our study. With the skill of sensitivity to problems in a task, a learner can comprehend the structure of the learning environment through trial and error. With fluency in generating ideas in a task, a learner can obtain numerous solutions as the task provides him/her an achievement. Having flexibility in a task, a learner can obtain various solutions by observing his/her learning trace in the learning goal space.

2.3. Creative Learning

Creative learning is defined as continuous learning with the discovery of unusual learning goals in the learner’s own [8]. In previous research [5], a human designed the achievements for a learner as a sequence of mazes. However, a creative learner requires a new achievement continuously. This implies that it is necessary for a creative learner to discover new achievements by himself/herself, but this is not an easy task. Therefore, we propose an interactive mechanism between a human learner and learning support system in which the system derives the achievements from the solutions obtained with two types of heuristics. Once the learner identifies an unusual solution, the system can derive new achievements from it.

2.3.1. Creative Learning Process

Figure 1 shows the flow of a creative learning process based on a continuous learning process. This process consists of three cycles. The innermost cycle is called a trial. A trial is defined as a transition sequence beginning from a start state to encounter either a goal state or a wall.

In this cycle, a learner repeats an action and his/her mental process including awareness until the learner either succeeds or fails in the task. The second cycle is called an achievement. An achievement is defined as a unit of the main task that is the learning of a maze with start and invisible goals. In this cycle, when a trial ends with a goal, the learner obtains the solution of the achievement. Then, the learner reflects the trial by the reflection of his/her learning traces in the learning goal space. This process is described in Section 3.3. If the current trial is not accomplished, the learner restarts the trial from the start state. The outermost cycle is the creative learning cycle. When a learner accomplishes a current achievement, the system generates a derived achievement according to the solution of the learner, and then, the learner can challenge the next new achievement. Section 3.3 describes this process.

2.3.2. Creative Learning Skill

A creative learning skill is defined as the learning skill to attempt to generate more creative solutions for the given tasks or problems having optimal or entrenched solutions. We propose an interactive mechanism consisting of two parts. The human part is to arrive at a new solution from the achievement. The role of the support system is to generate a new achievement derived from the solution of the human learner by randomly adding a sub-reward to it to support the learner to obtain more creative solutions.
3. Designing the Creative Learning Support System

3.1. Learning Environment by a Maze Model

For the learning environment of a human learner, we adopt a grid maze from the start to the goal state because it is a familiar example to obtain the path through a trial and error process. First, we define the maze, path in the maze, and solution of the maze. The maze has the shape of a two-dimensional maze defined by three types of states (start, goal, and normal states) and walls surrounding the states. This is described in detail in a proceeding section on the maze model. A path consists of states and an action transition sequence from the start state to the goal state. A solution is a path corresponding to the maze.

The maze model for creative learning consists of five elements: a state set, transitions and walls, an action set, and rewards. Fig. 2 shows the structure of a two-dimensional grid maze. An $n \times m$ grid maze with four neighbors consists of $n \times m$ number of $1 \times 1$ squares. It is called a simple maze that is surrounded by walls in a rectangle shape. Fig. 2(a) shows a $3 \times 2$ simple maze with a start and a goal. In a grid maze, every square touches one of their edges except for a wall. Each square in the maze model is called a state. A state can be visited at once. Transitions between states in the maze model are defined based on whether the corresponding square with four neighbors, \{up, down, left, and right\} is or is not connected by a wall. They are represented as a labeled directed graph, as shown in Fig. 2(b). An action set is defined as a set of labels to distinguish the possible transitions of a state. In a grid maze, the learner can take four types of actions: up, right, down, or left. Note that a trial is a transition sequence from the start state to either a goal state or a wall, and the action toward a wall results in the transition from the start state to restarting of the trial. A transition to the goal state results in the success of the achievement, following which the learner determines a solution and receives a main reward (+1).

3.2. Designing the Creative Learning Support System

This section describes the approach for automatically generating a new achievement as shown in Fig. 1. First, we describe a stage and an achievement in the creative learning task. A stage is a set of achievements of the same maze shape. An achievement of the creative learning task is defined as learning a maze to obtain a path from the start state to the goal state. An achievement consists of the maze shape and any generated sub-rewards. It is a unit of the learning process that is either an original achievement consisting of only the maze shape or a derived achievement that contains the generated sub-rewards. Fig. 3 shows the flow of generating a new achievement by the system. The inner loop in Fig. 3 illustrates the interactive process of generating a new achievement by the system from the solution the learner searched. After a solution is obtained by the learner, it is displayed in the learning goal space as the learning goal obtained for reflection of the learner. Then the system derives the achievement by adding a reward according to the type of solution. The system resets the achievement, and the learner attempts it. The outer loop in Fig. 3 depicts the progress of the learning stage. It has two directions. One is when the learner decides to leave a current stage. Another is the decision of the system when the learner obtains the same solution in the series. In this study, the sequence of the rectangle-shaped maze is predefined as $4 \times 4, 4 \times 5, 5 \times 5, 5 \times 6$, and $6 \times 6$.

3.3. Designing Automatic Generation of Derived Achievements

3.3.1. Classification of the Solutions of Creative Learning

This section describes the classification of the solutions of creative learning. First, we consider the size of the
Table 1. Classifying solutions based on their length.

<table>
<thead>
<tr>
<th>The types of a solution</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>The shortest solutions</td>
<td>The shortest paths from a start state to an encountering goal state</td>
</tr>
<tr>
<td>The redundant solutions</td>
<td>The paths besides shortest solutions and longest solutions</td>
</tr>
</tbody>
</table>

solution. Table 1 shows the classes of solutions based on their length. We classify them as shortest or redundant. Note that to convert a redundant solution into a learning goal, it is necessary to introduce some optimality.

Second, we introduce optimality into a solution to define the quality of the solution. This study adopts an average reward reinforcement learning framework. In this, an optimal solution is defined as a solution with maximum average reward. Note that its average reward is the sum of the acquired rewards divided by the solution length. Therefore, the shortest solution that can acquire rewards has a tendency to be optimal.

In the field of reinforcement learning, the approach to derive an optimal solution has been under investigation in recent years. However, it is not the end of learning with creative learning. Therefore, we focus on the learning gained after an optimal solution is found, and on redundant, i.e., non-optimal solutions to utilize them as they have not drawn attention as learning goals. The next subsection describes how to derive a learning goal from the shortest and redundant solutions.

3.3.2. Deriving a New Achievement by Negating the Shortest Solution

This subsection describes the method to generate a derived achievement. When a learner identifies the shortest solution, the system adds a negative sub-reward on one of the transitions in the identified path to negate it. This approximate negation of the optimal solution derives a new achievement creatively as the remaining redundant solutions encourage the learner to be creative by avoiding the negative sub-reward to obtain new solutions. Note that the negative sub-reward is placed randomly in the path, and its value is \(-1\).

3.3.3. Deriving a New Achievement from Justifying a Redundant Solution

This subsection describes the method to generate a derived achievement based on the justification of a non-optimal solution. When a learner obtains a redundant solution, the system adds a positive sub-reward on one of the transitions in the identified path to justify it. This crude justification of the redundant solution yields a new achievement creatively because there may be better solutions with a positive sub-reward than this redundant solution. Note that the positive sub-reward is placed randomly in the path, and its value is \(+1\).

3.4. Designing the Learning Goal Space

The learning goal space is the space in which the detected solutions are located to be displayed. In the learning goal space, the vertical axis is the solution quality and horizontal axis is the solution cost. The solution cost is the cost for implementing a solution. Solution quality expresses how many sub-goals the learner can achieve in the process of obtaining the solution. These two axes are generalized as the learning cost and learning quality, respectively. The learning cost partially depends on each learner. In this study, we simplify the learning cost, and define instead the solution cost as an independent axis. A point in the learning goal space is a set of solutions for which the solution quality equals the solution cost. In Section 4.3.3, we discuss the application of this proposed system to other tasks.

Figure 4 illustrates an example of the learning goal space. Si is the i-th solution identified by a learner. The value of S expresses the order in which the learner determines the solutions. The transition from S1 to S2 depicts that the direction of learning is to the right, and it implies that learning only increases the solution cost toward the horizontal learning goal. S3 transits from S2 toward the vertical direction along which only the solution quality increases. S4 transits from S3 to simultaneously increase both the solution cost and solution quality.

4. Experiment

The aim of the experiment is to evaluate the effectiveness of the three approaches for showing a learning record. The comparative experiment is conducted for four subjects. All the subjects are university students in their twenties.

4.1. Experimental Setup

4.1.1. Experimental Task

We explain the experimental task from two points of view, namely, the subject and experimenter point of views.
First, we explain the experimental task from the subject point of view. This experimental task is a maze task with multiple paths from the start state to the goal. The instructions for scoring are: if the subject attains the goal, the subject is scored +1; if the subject goes through the green rectangle, the subject receives a score of +1; if the subject goes through the purple rectangle, the subject receives a score of −1. The termination condition of the experimental task is to complete all the stages. The completing condition of the stage is not shown to the subject. During the experiment, a countdown relating to the completing condition is shown to the subject. When the countdown is finished, the stage makes progress to the next stage. When the subject attains the goal, the learning record is shown by the method described later.

Next, we explain the experimental task from the point of view of the experimenter. The score is added during the path of the solution. If the subject obtains a solution of an unknown path length, a positive sub-reward of +1 is added. If the subject detects a solution having a known path length, a negative sub-reward of −1 is added. The termination condition of the experimental task is to complete all the stages. The completing condition of the stage is not shown to the subject. During the experiment, a countdown relating to the completing condition is shown to the subject. When the countdown is finished, the stage makes progress to the next stage. When the subject attains the goal, the learning record is shown by the method described later.

Table 2. Maze size and the initial value to complete the stage.

<table>
<thead>
<tr>
<th>Stage number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maze size</td>
<td>4 x 4</td>
<td>4 x 5</td>
<td>5 x 5</td>
<td>5 x 6</td>
<td>6 x 6</td>
</tr>
<tr>
<td>Simple maze</td>
<td>simple maze</td>
<td>simple maze</td>
<td>simple maze</td>
<td>simple maze</td>
<td>simple maze</td>
</tr>
<tr>
<td>The initial value to complete the stage</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>13</td>
</tr>
</tbody>
</table>

4.1.2. Flow of the Experiment

The flow of the experiment is as follows:

Step 1. The subject reads the instructions for the experimental task.

Step 2. The subject starts the experimental task when he wants to start it. He is able to read the instruction for the experimental task during the experimental task.

Step 3. The subject accepts the experimental task.

Step 4. The subject answers the questionnaire after the experimental task.

Step 5. The subject answers the hearing investigation.

Next, the flow of the experimental task is as follows:

Step 3-1. The subject accepts any of the four actions: up, down, left, and right, with a four-way controller in the stage.

Step 3-2. When the subject identifies the path from the start to the goal, the learning record is shown.

Step 3-3. The subject closes the learning record.

Step 3-4. If the subject reaches the completing condition or if the limited time is over, go to Step 3-6.

Step 3-5. Return Step 3-1.

Step 3-6. The stage progresses to the next stage. The learning record is reset. If the stage is final stage, the experimental task is ended.

4.1.3. Compared Methods

This experiment is conducted using three methods that are compared. The three methods being compared are as follows. The order of obtaining the solutions is a natural number showing what number of the path from the start to goal state is identified.

i. Showing the scatter chart in the learning goal space

The learning goal space is a two-dimensional space consisting of two axes, the score and step length of an obtained solution. The position of the solution obtained by the subject is decided by the score and step length of the solution. The solution is plotted as a point in the learning goal space.

ii. Showing the score record graph in the order of obtaining the solutions

The score record is a two-dimensional space consisting of two axes, the score and order of obtaining the solutions. The score record shows the scores of the solution in the order of obtaining the solutions with a bar graph.

iii. Showing the uniqueness record graph for the order of obtaining the solutions

The uniqueness record is a two-dimensional space consisting of two axes, the uniqueness and order of obtaining the solutions. The uniqueness record shows the uniqueness of the solution for obtaining the solutions with a bar graph. The uniqueness is the quantitative value expressing the novelty of the solution. The novelty of the solution is calculated as follows [9]:

\[
Novelty(s, S) = \frac{1}{|S| - 1} \sum_{s_i \in S} dist(s_i, s) \ldots (1)
\]

where \(Novelty(s, S)\) is the novelty of the solution, \(S\) is the set of the solutions, \(|S|\) expresses the number of the solutions in \(S\), \(s\) is the most recent obtained solution, and \(dist(s_i, s)\) is the Euclid distance between \(s_i\) and \(s\) in the learning goal space. This is why the learning goal space is not a grid space.
The difference between the learning goal space and score record graph is the number of the learning goals shown to the subjects. The axes of the learning goal space are the score and step length of the solution. Both the axes are learning goals. In contrast, the axes of the score record graph are the score and order of obtaining the solutions. Please note that the score is a learning goal; however, this is not so for the order of obtaining the solutions.

The difference between the learning goal space and uniqueness record graph is the approach to exhibit the novelty of the solutions. In the learning goal space, the positions of the determined solutions express the novelty. Showing the novelty in the learning goal space is implicit. In contrast, in the uniqueness record graph, the quantitative values express the novelty of the solutions. Depicting the novelty in the uniqueness record graph is an explicit requirement.

The difference between the score record graph and uniqueness record graph is in the complexity of the learning goal. In the score record graph, the score of the solution is the accumulative score acquired by obtaining the sub-reward and goal. The score is simply calculated. In contrast, in the uniqueness record graph, the uniqueness is calculated by Eq. (1) using the score and step length. The uniqueness has a complex calculation.

4.1.4. Instruction for the Subjects

A brief summary of the instruction for the subjects includes the following points:

- The objective of the task is to complete all stages.
- If you reach the goal, you obtain +1 score.
- If you go through the green rectangle grid, you obtain +1 score.
- If you go through the purple rectangle grid, you obtain −1 score.
- The time limit is 6 min in each stage.
- You must look at {the learning goal, score record, uniqueness}* window. *One of three compared methods is shown.
- Step length is the number of actions from the start to the goal. (Only the learning goal space and uniqueness score)
- Uniqueness expresses how unique the path is.

4.1.5. Measurement Parameters

The major measurement parameters of the experiment are as follows:

(a) The number of the trials
(b) The number of the obtained solutions
(c) The number of the path
(d) The number of the learning goal
(e) Novelty of the learning goal space
(f) The number of the types of path lengths

Note that the number of the types of path lengths shows the accumulated number of the all completing conditions. In the case that the subject completes all the stages, the number of the types of path lengths is 45. Novelty of the learning goal space (e) is the average novelty of the learning goal space among all the stages.

4.2. Experimental Results

We analyze the quantitative effectiveness of the compared methods. Table 3 shows the experimental results. Note that measurement items (a)–(f) are described in Section 4.1.5. Table 3 shows that Subject1 performs the experimental task by examining the learning record in the learning goal space. Subject2 performs the experimental task by looking at the learning record in terms of the uniqueness record graph. Subject3 and Subject4 perform the experimental task by observing the learning record in the score record graph. Subject1, Subject3, and Subject4 complete all the stages within the limited time. Subject2 does not complete Stage5 because he crosses the time limit. As shown in Table 3, Subject1 in the learning goal space obtains the maximum number among the four measurement parameters, namely, number of trials (a), number of the obtained solutions (b), number of the path (c), and number of the learning goals (d) out of six. Subject2 in the uniqueness record graph obtains the second most number in the same four measurement items out of six. Both Subject3 and Subject4 in the score record, obtain the smallest number in the same measurement items out of six.

<table>
<thead>
<tr>
<th>Measurement items</th>
<th>(a)</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
<th>(e)</th>
<th>(f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject1 (The learning goal space)</td>
<td>148</td>
<td>141</td>
<td>119</td>
<td>98</td>
<td>7.21</td>
<td>45</td>
</tr>
<tr>
<td>Subject2 (The uniqueness record graph)</td>
<td>132</td>
<td>129</td>
<td>112</td>
<td>90</td>
<td>7.11</td>
<td>44</td>
</tr>
<tr>
<td>Subject3 (The score record graph)</td>
<td>92</td>
<td>88</td>
<td>84</td>
<td>73</td>
<td>7.01</td>
<td>45</td>
</tr>
<tr>
<td>Subject4 (The score record graph)</td>
<td>100</td>
<td>94</td>
<td>91</td>
<td>81</td>
<td>7.22</td>
<td>45</td>
</tr>
<tr>
<td>The average of Subject3 and Subject4</td>
<td>96</td>
<td>91</td>
<td>88</td>
<td>77</td>
<td>7.11</td>
<td>45</td>
</tr>
</tbody>
</table>
Table 4. Rate of obtaining the learning goals in each stage.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Stage1</th>
<th>Stage2</th>
<th>Stage3</th>
<th>Stage4</th>
<th>Stage5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject1</td>
<td>0.42</td>
<td>0.73</td>
<td>0.84</td>
<td>0.83</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>Subject2</td>
<td>0.67</td>
<td>0.71</td>
<td>0.90</td>
<td>0.44</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>Subject3</td>
<td>0.70</td>
<td>0.84</td>
<td>0.79</td>
<td>0.81</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>Subject4</td>
<td>0.82</td>
<td>0.86</td>
<td>0.94</td>
<td>0.92</td>
<td>0.84</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Rate of determining the same path in each stage.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Stage1</th>
<th>Stage2</th>
<th>Stage3</th>
<th>Stage4</th>
<th>Stage5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject1</td>
<td>0.31</td>
<td>0.09</td>
<td>0.12</td>
<td>0.10</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Subject2</td>
<td>0.17</td>
<td>0.13</td>
<td>0.00</td>
<td>0.12</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Subject3</td>
<td>0.00</td>
<td>0.05</td>
<td>0.11</td>
<td>0.00</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Subject4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Average score per obtained solution in each stage.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Stage1</th>
<th>Stage2</th>
<th>Stage3</th>
<th>Stage4</th>
<th>Stage5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject1</td>
<td>−0.92</td>
<td>1.09</td>
<td>0.48</td>
<td>−0.66</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Subject2</td>
<td>1.50</td>
<td>2.79</td>
<td>3.67</td>
<td>2.64</td>
<td>2.55</td>
<td></td>
</tr>
<tr>
<td>Subject3</td>
<td>1.60</td>
<td>2.63</td>
<td>2.05</td>
<td>3.04</td>
<td>2.26</td>
<td></td>
</tr>
<tr>
<td>Subject4</td>
<td>1.91</td>
<td>2.91</td>
<td>3.33</td>
<td>3.48</td>
<td>2.83</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Average novelty per obtained solution in each stage.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Stage1</th>
<th>Stage2</th>
<th>Stage3</th>
<th>Stage4</th>
<th>Stage5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject1</td>
<td>3.10</td>
<td>6.59</td>
<td>6.46</td>
<td>8.91</td>
<td>9.01</td>
<td>7.21</td>
</tr>
<tr>
<td>Subject2</td>
<td>4.43</td>
<td>5.15</td>
<td>7.21</td>
<td>9.24</td>
<td>9.52</td>
<td>7.11</td>
</tr>
<tr>
<td>Subject3</td>
<td>4.30</td>
<td>5.38</td>
<td>8.24</td>
<td>8.57</td>
<td>8.54</td>
<td>7.01</td>
</tr>
<tr>
<td>Subject4</td>
<td>3.86</td>
<td>6.90</td>
<td>6.73</td>
<td>8.59</td>
<td>10.02</td>
<td>7.22</td>
</tr>
</tbody>
</table>

Table 4 shows the rate of obtaining the learning goals in each stage. The rate of the learning goals indicates the ratio of the number of the learning goals to the number of the identified solutions. Its lower limit is 0 and upper limit is 1. As shown as Stage5 in Table 4, the average rate of obtaining the learning goals of Subject1 is as high as Subject2. The rate of Subject3 and Subject4 is higher than both of Subject1 and Subject2. The subject with the score record graph has the highest average rate of all the stages among the three compared methods.

Table 5 shows the rate of obtaining the same path in each stage. The rate of determining the same path is the ratio of the number atoms in the same path to the number of the obtained solutions. As shown in Table 5, Subject1 in the learning goal space has the highest average rate of obtaining the same path for the four subjects. Subject2 in the uniqueness record graph has the second highest average rate. Both Subject3 and Subject4 in the score record graph have the lowest average rate. Table 6 shows the average score per obtained solution in each stage. The average in Table 6 is the average of the average scores per obtained solution in all the stages. It can be seen from Table 6, the average score of the subjects to whom one learning goal is shown (Subject2, Subject3, and Subject4) is more than that of Subject1 to whom two learning goals are shown. Table 7 presents the average novelty of obtained solutions found in each stage. The average in Table 7 is the mean of the average novelty in all the stages. As shown in Table 7, the differences in the average novelties of the compared methods are small.

We describe the results of the questionnaire and the hearing investigation after the experimental task. Table 8 presents the overview of the answers of the questionnaire and hearing investigation.

It is clear from Table 8 that both Subject1 in the learning goal space and Subject2 in the uniqueness record graph consciously decide the approach to search solutions. Both the subjects are concerned about the importance of the compared methods shown to them in the latter stages.

In contrast, two subjects in the score record graph do not have any concerns regarding the compared methods in the latter stages.

From these results, it is understood that showing the learning goals and feedback of the learning results in a complex form is effective for the continuation of the in-
Table 8. Overview of the answers of both the questionnaire and hearing investigation.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>The overview of the answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject1</td>
<td>Subject1 takes random actions and searches the solutions to make clear where the score adds in the former four stages. He searches the solutions to fill a blank space in the learning goal space.</td>
</tr>
<tr>
<td>Subject2</td>
<td>Subject2 tries to make clear where the score adds to obtain more visible green rectangle in the former three stages. In both Stage4 and Stage5, he tries to find the solutions having different path length with the obtained solutions to obtain higher uniquenss.</td>
</tr>
<tr>
<td>Subject3</td>
<td>Subject3 searches the solutions to obtain higher score first. After she realizes that obtaining high score is not the completing condition of the stage, she searches the solutions without thinking.</td>
</tr>
<tr>
<td>Subject4</td>
<td>Subject4 think that she is able to complete the stage if she finds many solutions. She searches the solutions without thinking.</td>
</tr>
</tbody>
</table>

4.3. Discussions

4.3.1. Effect of the Learning Goal Space that Visualizes the Novelty of an Obtained Solution

To evaluate the effect of the learning goal space, we discuss whether each subject sets the heuristic learning goals or not and the way he/she performs the experimental task continuously toward the task accomplishment. Table 8 shows that Subject1 to whom the novelty of the obtained solutions by the learning goal space is indirectly presented sets the heuristic learning goals through all the stages. The heuristic learning goals of Subject1 are to clarify the position of the added score and to fill the blank space in the learning goal space. First, we focus on the former heuristic learning goal. As shown in Table 5, it appears that Subject1 observes how to add the score to the obtained solution in both Stage1 and Stage2 by finding the same path. It appears that Subject1 takes random actions for finding a different path with the found paths in both Stage3 and Stage4. Next, we focus on the latter heuristic learning goal. As shown in Table 4, it appears that Subject1 attempts to fill the blank space in the learning goal space by taking advantage of the learning goal space. In addition, as shown in Table 6, it looks that Subject1 is not conscious of obtaining the score. Similar to Subject1, Subject2 to whom the novelty of the obtained solutions was presented, sets the heuristic learning goals through all the stages. As shown in Table 8, the heuristic learning goals are to maximize the score and uniquenss. As shown in Table 6, it appears that Subject 2 attempts to maximize the score in the former three stages. As shown in Table 7, it appears that Subject2 searches the solutions to attempt to maximize the uniquenss in both Stage4 and Stage5.

In contrast, other subjects to whom the novelty of the obtained solutions was not presented, set their learning goals differently. Subject3 sets heuristic learning goals in former three stages. As shown in Table 8, the heuristic learning goal is to maximize the score. As shown in Table 6, it appears that Subject3 try to maximize the score. Subject4 does not set a heuristic learning goal, as shown in Table 8.

Therefore, it is suggested that the subjects who are presented the learning goal space (Subject1) or presented the novelty of the obtained solution (Subject2) continue to search for solutions according to their learning goals until the final stage in the experiment.

4.3.2. Choice of the Distance Function

We discuss whether the Euclidean distance is appropriate as the distance function between the most recent obtained solutions and a set of the obtained solutions. Lehman considers the distance function as a domain-dependent measure [9]. In the field of clustering, the appropriate definition of the distance is generally dependent on the presence or absence of correlation between the spatial axes [10]. If the correlation is large positive or negative, the Mahalanobis distance is the appropriate distance function. In case of no correlation, the Euclidean distance is appropriate. In this experiment, the correlation coefficients between the two axes of the learning goal space of the four subjects are 0.5, 0.5, 0.3, and −0.3 (Overall correlation coefficient is 0.2). Two correlation coefficients out of the four have a moderate positive correlation, and the other two correlation coefficients have a poor correlation. Therefore, the appropriate distance function should be the Mahalanobis distance. However, the appropriate distance function is the Euclidian distance in this continuous learning task because it is necessary to measure the novelty of the obtained solution in the process while incrementally generating the known solution.

4.3.3. Application to Other Tasks

In this section, we discuss the application of the proposed system to other tasks. We show the necessary conditions for implementing the creative learning support system in a task as follows:

i. quantifiable solution cost

ii. quantifiable solution quality

iii. sufficient solutions

iv. sufficient learning sub-goals

i–ii are regarding the axes of the learning goal space. They show that the axes are quantifiable. iii shows that it is necessary to plot sufficient solutions in the learning goal space for the purpose of displaying the learning trace of the learner. iv is for the system to generate the task by adding a sub-reward as a sub-goal.
4.3.4. Future Works

There are several future works. The first one is to clarify the definition of creative learning, particularly the definition of “unusual solutions.” Second, we will define the value of a sub-reward. The value of sub-reward $V$ at sub-reward $r_i$ will be given by

$$V(r_i) = \frac{N_u(r_i)}{N_s(r_i)}$$

where $N_u$ is the number of unknown solutions containing sub-reward $r_i$ and $N_s$ is the number of solutions containing sub-reward $r_i$. The reason the above equation provides the value of sub-reward is that the value of the sub-reward becomes larger with increasing number of the identifiable unknown solutions with the sub-goal as the cue.

5. Conclusions

This paper presented an interactive method for humans to creatively learn with a learning support system. We described the approach to design the learning support system towards acquiring creative skills with learning. We proposed a learning goal space that visualizes the distribution of the obtained solutions on it, and then examined the method for supporting the exploration of the learning goals by a learner to present the novelty of an obtained solution. According to the experimental results, each subject continues to find the solutions and explore his learning goals based on the provided learning feedback. Therefore, it is suggested that for a continuous learning task, our supporting method is effective when presenting the novelty of an obtained solution directly or indirectly by the learning goal space. In the future, we will clarify the definition of creative learning, and in particular of “unusual solutions.”

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