Title
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The Microgenetic Analysis of an Origami Task

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Abstract

An experiment was conducted in which subjects repeatedly constructed Origami boxes, following example models displayed by the experimenters. A microgenetic analysis was performed on videotapes of the experiment. Results show an increase in speed generally following the power law of practice, and the rearrangement and combination of operations into larger units. They give evidence for the importance of external information in the tasks people perform, and contain a possible example an occasion of insight prompted by earlier breakdowns. Most importantly, the experiment shows how an apparently straightforward improvement in performance can be dissected to uncover the myriad factors and effects that underlie it.

Introduction

Many researchers have investigated the ways people improve when performing repeated tasks. Newell and Rosenbloom (1980) showed that the power curve of practice can be applied broadly to many aspects of performance, and applied the chunking theory of psychology as a partial explanation for this phenomenon. Gentner (1982), studying the evolution of typewriting skill, and Agre and Shrager (1990), who performed a microgenetic analysis of a copying machine task, demonstrated the ways in which tasks undergo qualitative changes as they are performed over time. Norman (1988) and Zhang (1990) discussed the ways in which external information is used in problem solving tasks, not only as a memory aid, but also as a mechanism by which the nature of the task itself is changed. There has also been considerable investigation into the ways in which people's mental models of the tasks they perform develop and evolve over time (Johnson-Laird (1988), Simon (1985), Kintsch and Greeno (1985), and others).

We set out to see how many of the phenomena identified in the substantial literature on skill acquisition and development would appear in a relatively simple, short term study based on observing subjects as they repeatedly constructed origami boxes. This task was chosen for several reasons. Firstly, the task was complex enough so that the task could evolve over time, yet simple enough so that it could be learned quickly by novices. Secondly, the task involves easily observable manual manipulations which would, it was hoped, provide clues to the subjects' thinking as they performed the task. Finally, the task contains three distinct yet related stages, and it was hoped that subjects would come to understand the differences and relationships among the stages. The central, and most complex, stage was comprised of a set of repetitive steps which had to be repeated in each of four places, but allowed the subjects some flexibility in determining the specific order in which they were performed. Finally, the complete task could be performed in several minutes, so many trials could be run and analyzed in the time available for this research. It was felt that many repeated trials were desired to increase the likelihood that patterns in performance would emerge and be identified with some assurety.

Even in this relatively simple, short-term experiment, we found evidence for many of the features of skill acquisition and development identified by previous researchers. The time in which each trial was performed decreased, roughly following the power curve law of practice. The task evolved qualitatively over time. There was evidence of chunking as operations were combined into identifiable, frequently repeated patterns. We also observed a clear occurrence of insight, and the context in which it took place and the effects it had on overall performance gave credence to established theories on the role of insight in problem solving and skill development.

Experiment

Procedure

Subjects were presented with a set of ten models showing each stage in the construction of an origami box. The models were arrayed in order from left to right on a table at which the subjects sat; each model was also numbered to indicate the order in which the steps could be performed to complete the origami box. This method of instruction was chosen after attempts to devise a set of clearly understandable, written instructions proved quite difficult. Also, experimentation with published origami instructions showed them to be confusing and hard to follow. It was also hoped that it would be easy to monitor the use of the models by the subjects, by observing when they looked up at the models or took them in hand. The subjects were given a stack of 8.5 inch square sheets of used copier paper with printing of some sort on one side. An experimenter sat next to the subjects at all times, and was available to answer questions and provide assistance as requested.

The subjects were asked to repeatedly make origami boxes, using the models in front of them as guides. The subjects were told that their times were being recorded, and were given the stated goal of completing a box in under 75 seconds as the criterion for terminating the experiment. The subjects were encouraged to ask questions as needed if they encountered difficulties in understanding the instructional models. They were also told to feel free to deviate from the exact sequence of steps represented by the models if they felt that doing so would be faster or easier for them; it was emphasized that the time in which they completed the boxes was important and not the specific steps they followed to make them.

The entire experiment was videotaped with the permission and knowledge of the subjects. (The videotape camera was clearly visible in the room, and red lights visible to the subject indicated when the machine was recording.)

After the main trials, the subjects were asked to describe the procedure for making an origami box from memory, with neither paper nor the instructional models in front of them. The subjects were then given a sheet of paper and asked to make an origami box while describing aloud the steps they were taking.

Subjects

Two subjects participated in the experiment. Both were female college graduates in their mid-twenties, and both were left-handed. Neither subject had extensive prior experience with origami, and neither subject knew before the experiment how to construct an origami box.

The Task

The process of making a box was divided into nine steps, grouped into the stages of *preparation*, in which scoring folds are made which facilitate later structural folds, *folding*, in which the major structural folds of the box are made, and *inflation*. The usual way of turning the flat structure produced by folding process into a three-dimensional box is to blow sharply into one end. These steps are diagrammed in Appendix A. The folding stage (steps 5-8) involved four folds that must be made in each of four places on the paper shape. The nine steps used to make the origami box are:

preparation: 1. horizontal fold in half
2. diagonal fold
3. diagonal fold
4. "collapse" to a triangular shape
folding: 5. fold bottom corners up (in four places)
6. fold side corners to middle (in four places)
7. fold top corners down (in four places)
8. fold corners into "pockets" formed in step 6 (in each of four places)
inflation: 9. inflate into box

We devised a notational scheme to represent the sequence of steps in the order in which they occurred, as it is in the changes to this order that some of the more interesting results appeared. Diagrams of selected trials using this notation accompany the text. Figure 1. illustrates this notation.

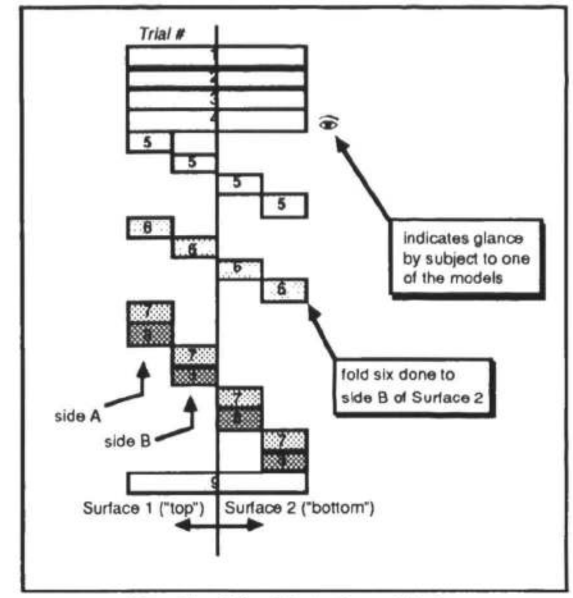

Fig. 1 The Notational Scheme

In this example, the subject performed steps 1 through 4, then step 5 in all four places, then step 6 in all four places, then steps 7 and 8 together in each of the four places, and finally step 9 to complete the box. The "eye" symbol ( ) indicates that the subject glanced at one of the models at some point while performing step 4.

Results

The first subject was analyzed in the most detail, and it is her performance that will be discussed in the most depth here. Subject one showed a clear increase in overall speed, roughly following the power curve of practice. Speeds for individual stages within the trials also tended to increase, though at different rates and following different trends than did the overall speedup. These results are plotted on a log-log scale in figure 2.

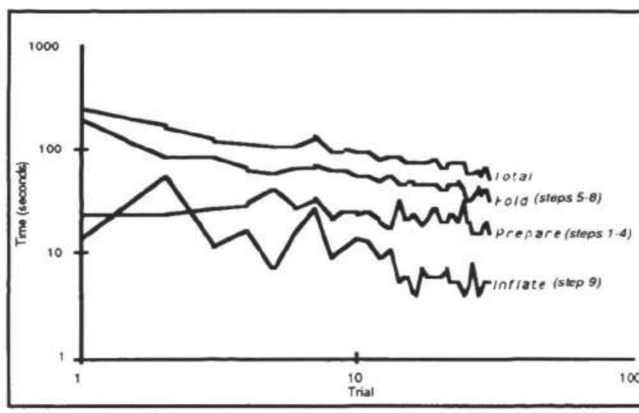

Figure 2. Times for subject one on a Log-Log Scale

At first, the subject glanced frequently at the models, but these glances dropped off rapidly to only three by the fifth trial, and to only one in trials seven, eight and ten. After this they were eliminated completely except for during trial twenty-four, which will be discussed further below. The glances were mostly made during the first six steps; in fact, after the third trial the subject did not glance at the models at all during the last three steps of making the boxes (steps 7-9). Many of the glances were "look-ahead" glances, in which the subject looked up at a model as she was finishing the fold she was making, in preparation for beginning the next fold (Figure 3).

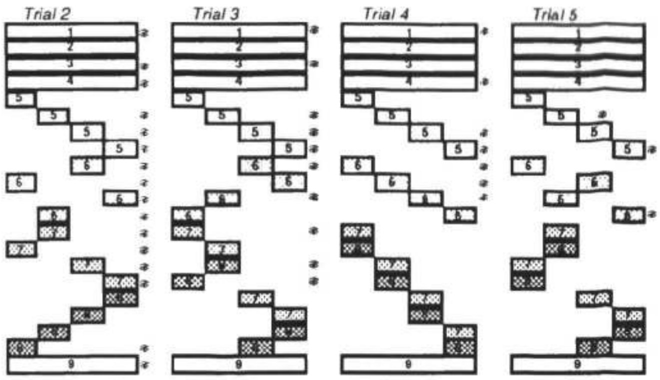

Fig. 3 Glances during early trials (shown by 👁's).

The subject started to make errors in only two of the trials. In the first trial, when the subject was first learning the task, and later in the ninth trial, the subject started to make a fold on a corner out of sequence (eg. fold 7 before fold 6 had been made), but she almost immediately realized her mistake and made the proper fold.

There was clear evidence of qualitative changes in the task over time. The incidence of "chunking", by which we mean places in which operations were combined and performed in groups rather than singularly for each of the corners, increased, as can be seen in the detailed summary of trials in the appendix. At first, these chunks consisted of two operations being performed on a given corner before moving on to another corner. In the seventh trial, a larger chunk emerged, which was used for both the top and bottom surfaces of the construction (Figure 4).

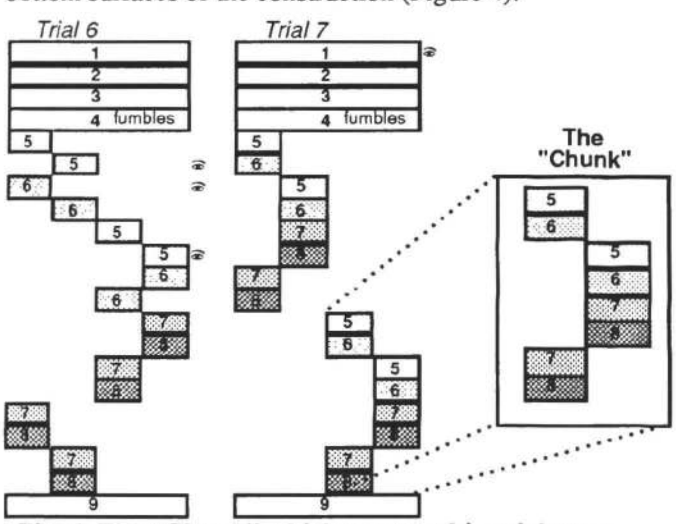

Fig. 4 The "Chunk" which appeared in trial seven.

This chunk was then used consistently for *each and every one* of the subsequent trials on the bottom, or second, surface. It was not, however, followed again for the top surface until trial thirteen, which was preceded by a twenty-five minute break during which the subject walked around, talked with the experimenters about topics unrelated to the experiment, and drank a cup of decaffeinated coffee (Figure 5).

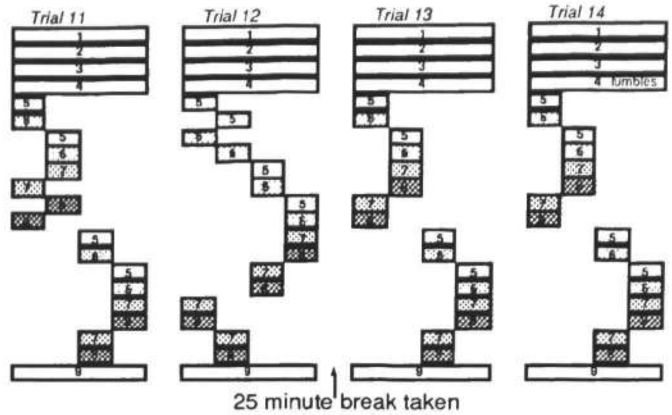

Fig. 5 Increased use of the "chunk" after a break.

From trial thirteen on, this chunk was used most of the time for the top surface up to trial twenty-four. In each of the three cases during these trials in which this chunk was not used for the top surface, the subject had encountered some difficulties in an earlier step. This included fumbling during step four (trials 19 and 24) and a corner jamming during step five (trial 17).

The fourth step, which consisted of collapsing the paper to a triangular shape, caused the subject difficulties in many of the trials. This step was often accompanied by noticeable fumbling. The subject noticed this problem early on, as seen by the following exchange which occurred after trial six:

S: Did you guys also have trouble with that middle folding part, in step 4?

E: Uh... Different people have trouble with different parts.

S: That's interesting...

There was some evidence that the subject understood the purpose of the first three steps as creating creases to make this easier and neater. In trial five, the subject fumbled during step 4 and *then went back to rescore the diagonal folds she had made in steps 2 and 3.* In fact, the subject had, from the beginning, been making the first fold in the wrong direction. Instead of helping the paper neatly fall into place, the fold was actually working against the subject, at best not helping and occasionally hindering her efforts to collapse the paper into the triangular shape she needed to proceed. This was something the subject did not realize until the twenty-fourth trial (Figure 6).

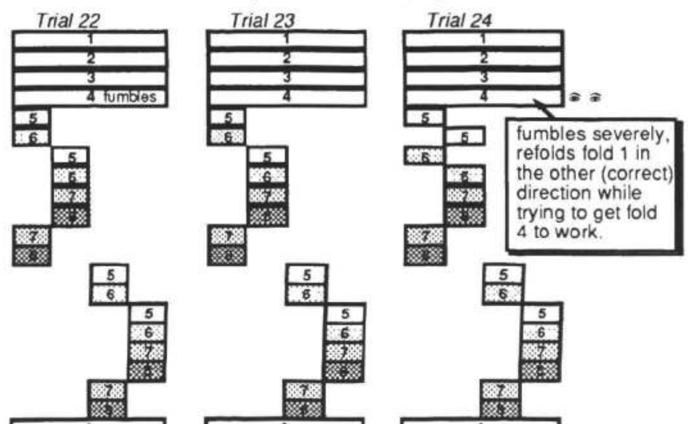

Fig. 6 Insight after fumbling in trial twenty-four.

In this trial, the subject fumbled severely while performing step 4 and in her attempts to guide the paper into place, opened it up and forcefully folded the paper in half down the center. The subject then glanced up at the models (for the first time since trial ten), collapsed the paper more easily into the triangular shape, and glanced up at the models again before proceeding with steps 5 through 9. After completing this trial, the subject had an exchange with the experimenter in which she said:

S: That cost me time, but I just realized something. Either I've been misunderstanding how this fold was supposed to be made, or it's just simply easier if you do it the other way. It may eliminate my fumbling.

The subject immediately incorporated the corrected step 1 fold direction into her procedure. Interestingly, this new addition seemed to perturb the chunking the subject had been using, causing the subject to deviate from using the chunk described above. As before, this deviation only affected the first surface; the subject continued faithfully to use the chunk on the second surface. Discovering the proper direction for the fold in step one helped the subject in two ways. Firstly, it reduced the time required, on average, for step 4. Secondly, it made the times for step 4 much more consistent than they had been. This is an effect that the subject herself realized. After trial twenty-seven, the subject commented about the newly discovered fold direction:

S: I was continuing to do this .../demonstrates the wrong direction fold/... which meant this fold, this part, was inside-out, and I had to play with it, sometimes it worked easily and sometimes I fumbled quite a bit.

After performing the trials, the subject was asked to describe, from memory, the steps taken to make an origami box, with neither paper nor any of the models in front of her. The subject expressed the feeling that this would be difficult, and that she was not sure if she could do it accurately. While describing the steps she took, the subject used her hands extensively, following many of the motions she would actually use to construct an origami box.

Discussion

The results from the trials with subject one showed evidence for many of the phenomena discussed in the vast literature on the acquisition and development of skills. Performance overall increased, roughly following the power law of practice, yet this overall increase represented the cumulative impact of several different qualitative effects. As mentioned above, there was clear evidence for the combination of individual operations into larger procedural units or chunks. This chunk was first used consistently for the first surface after a break had been taken, lending some support to the idea that the chunk was stored as a single unit, and retrieved as a unit by the subject after she returned from her break. The hypothesis that this chunk represented a rather automated procedural unit is strengthened by the fact that subsequent deviations from use of this chunk were traceable to fumbling of some sort in an earlier stage. It appeared as if these instances of fumbling caused the subject to think consciously again about what had become a rather automatic process. She therefore neglected to use the automatic chunk but returned to the more deliberate operations she had followed earlier in the task.

It was after the chunks had been used repeatedly on both surfaces that the subject remarked that the task was "just now becoming mindless." The fact that this remark happened to be made after a trial in which she did, in fact, deviate from using the chunk on the first surface need not minimize its significance. It is even possible that the fumbling which occurred in that trial, by requiring the need for conscious intervention, led to the realization that she had been performing the task automatically. It is also possible that she felt that she had been performing the task *too* automatically, causing her performance to become more prone to mistakes and fumbling. She seems to express the belief that the task becoming more automatic was a factor in its becoming sloppier when she later states that she was "starting to, like, just do it now, without thinking" but that "it's getting sloppier also though." Interestingly, the fastest time was recorded for the subject in the last trial, in which she used the chunk for both surfaces and which she performed, in part, while talking, strengthening the impression that the task had truly become an automatic one.

The instance of insight observed in step twenty-four, in which the subject discovered that she had been incorrectly folding folds 2 and 3 in the same direction as the first fold, contained many of the characteristics identified early on by Ruger (1910), Woodworth (1939), and others both in its causes and its effects on subsequent performance. This insight was led to by the subject's manipulations while trying to overcome severe problems in completing step 4. It is significant that the subject had encountered similar difficulties with this step several times before, but never severely enough to cause the additional folding which led to the subject's insight. The time required for the "prepare" stage (steps 1-4) was therefore higher in trial twenty-four than it had been in the immediately preceding trials. This insight improved performance in subsequent trials in two ways – the prepare stage was made not only faster but also more consistent.

Several insights into the mental models the subject was using to complete the task can be drawn from observations of her behavior, and through protocol analyses of the things she said during and after the task. As mentioned above, the subject showed an understanding of the relationships between the tasks, realizing, for example, that the folds made in the first steps would assist with collapsing the paper in step 4. The subject seemed to realize early on that steps 5-8 could be combined in any way she wanted, as long as they were performed in the correct sequence within each corner. The subject moved her hands through the motions of constructing an origami box when she attempted to describe the procedure from memory, implying that a somewhat kinesthetic procedure was involved in the subject's internal representation.

There was also substantial evidence for the role external knowledge played in the subject's performance of the task, in many of the same ways that were identified by Norman (1988) and Zhang (1990). The paper being folded itself provided an indication of where within the procedure the subject was. It also provided certain affordances, helping to insure that the proper sequence was followed since it made some steps impossible before others had been performed. It also provided constant feedback, in that a wrong fold would lead to an unusual shape the subject could recognize as one not normally encountered when the procedure was followed correctly. This was seen in the way the subject quickly recovered after starting to make an error in trials one and seven when she realized that either she could not yet make the fold she was intending to make, or that it would not look right if she did. The subject alluded to the use of these affordances when recalling the procedure from memory. She mentions folding "the four pieces you can" and talks about folds meeting and lining up with other folds that had been made previously. A careful reading of the transcript of this portion of the protocol analysis shows obvious mistakes made by the subject in describing the shapes encountered at stages of the procedure that caused her no difficulties during the actual trials. It seems likely, therefore, that the subject was making use of information beyond that contained in her internal representation. It appears that the subject herself acknowledged the importance of this external information, in that she was not sure if she could accurately describe the task totally from memory, and that after she attempted to do so she asked, "Did I get it?".

Summary

The illustrative experiment discussed in this paper demonstrated many of the phenomena previously described in the literature on skill acquisition. It showed how operations can be rearranged and combined into larger chunks, and how these chunks can then be stored and utilized almost automatically. It revealed a clear example of the effect that failure can have in prompting moments of insight that lead to qualitative changes in the tasks that are performed. It gave evidence for the importance of external information in the tasks people perform. Most importantly, the experiment showed how an apparently straightforward improvement in performance can be dissected through microgenetic analysis to uncover the myriad factors and effects that underlie it.

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Appendix A: Steps to Make an Origami Box.