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# Explanatory analysis of the manner in which an instructor adaptively organizes skilled motion teaching process

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ABSTRACT

Mastering a skilled motion usually requires a step-by-step progression through multiple learning phases with different subgoals. It is not easy for a learner to properly organize such a complex learning process without assistance. Hence, this task is often facilitated interactively by a human instructor through verbal advice. In many cases, the instructor's teaching strategy in relation to decomposing the entire learning process into phases, setting a subgoal for each learning phase, choosing verbal advice to guide the learner toward this subgoal, etc. remains intuitive and has not yet been formally understood. Thus, taking the basic motion of wok handling as an example, this paper presents several concrete teaching processes involving an advice sequence and the corresponding changes in the motion performance in a feature variable space. Thereby, the paper analyzes and represents the actual strategy taken in an easy-to-interpret form. As a result, it confirms that the instructor determines the set of advice elements to be given based, not simply on the observable characteristics of the latest motion performance, but more adaptively upon the interaction history with the learner.

*Relevance to industry:* Teaching a skilled motion efficiently is essential in various industrial sectors such as those involving manual assembly. An experienced instructor may adaptively organize the entire interactive process of teaching a learner to accelerate the learning of correct motion skills.



## 1. Introduction

Simplification is one of the basic principles for designing human operations that need to be performed in a manufacturing system. However, many operations requiring motion skills still need to be performed on the shop floor, and mastering them efficiently is a crucial issue (Mital et al., 1999; Watanuki and Kojima, 2007; Zhong and Stone, 2013). In other fields like nursing (Hodder et al., 2010), sports (Cassidy et al., 2006), shooting (Goonetilleke et al., 2009), dancing (Choi et al., 2007), music (Visentin et al., 2008), cooking (Wu and Hsieh, 2002), manual handling (Authier et al., 1996), etc., mastering and refining some basic skilled motions form an important basis, not only for professionals to realize good performances, but also for amateurs to enjoy performing. Therefore, many studies have been conducted to understand various human motions and obtain formal descriptions of them (for example, Yen and Radwin, 1999; Goonetilleke, 1999; Zajac, 2002; Balasubramaniam and Turvey, 2004; Yamamoto and Fujinami, 2008).

However, the ability of a person to describe a skilled motion in detail does not necessarily imply that they are able to perform it well (Bernstein, 1996; Suwa, 2008). Rather, for the person to become capable of skillfully performing the motion, they will need to be trained by repetitively practicing the motion. That is, a motion skill is something that needs to be developed through practice (Bernstein, 1996). Further, if the practice is not properly organized, it may take a long time or may even be difficult for them to obtain the motion skill. Thus, to effectively assist a person master a skilled motion, the motion as well as the process of mastering it must be well understood. In terms of on-job instruction (Shepherd, 1986), *an instructor is required to observe and correct the learner as he attempts the task for himself, and should have an instruction manual to prompt any crucial key operating points.*

An approach that is often adopted for facilitating the process of mastering a skilled motion involves providing the learner with some information about the desired performance of the motion and/or the manner in which their current performance deviates

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from the desired one. In this approach, the desired performance is often characterized by the manner in which well-trained experts perform the motion. For example, Nalanagula et al. (2006) successfully improved the visual search quality of some novices by instructing them using a simplified search path representing the manner in which an expert inspector moves her eyes across the printed circuit board to be tested. Although this approach works for some motion skills, as reported in the example, it alone may not be sufficient for others because this approach treats the learning process for a skilled motion as a single-step transformation. That is, the features of the skilled motion are characterized by some variables, and the learning process is captured as a linear movement from the point representing the learner's current performance toward a goal corresponding to the desired performance in the space spanned by the feature variables. However, not every skilled motion can be acquired in such a straightforward manner.

It is more often the case in practice that multiple learning phases with different subgoals should undergo a step-by-step manner to master a skilled motion (Bernstein, 1996). In this case, identifying and providing the final goal will not be sufficient to facilitate the process of learning the motion. The method used to subdivide the entire learning process into phases should also be addressed, along with how to define the subgoal for each phase, etc. That is, the learning process should be more strategically supported. However, a method for realizing this strategic support has not yet been formally understood. Instead, it is handled intuitively by a human instructor through verbal advice. Lim and Hoffmann (1997) and Nickles et al. (2003) confirmed the effectiveness of specific verbal advice in refining the quality of a manual assembly operation and a visual inspection operation, respectively. However, to the best of our knowledge, thus far, little research has been conducted on the teaching strategy behind the verbal advice, that is, how to decompose the entire learning process into phases, how to set a subgoal for each learning phase, how to choose verbal advice to guide a learner toward the subgoal, etc.

Thus, taking the basic motion of wok handling as an example, this study takes a first step toward obtaining a formal understanding of the teaching strategy for a skilled motion. It first observes several concrete processes involved in teaching the example motion using advice and captures them using an advice sequence and the corresponding changes in the motion performance in a feature variable space. Then, it analyzes and represents the actual strategy in an easy-to-interpret form. An earlier version of this work was presented in Mizuyama et al. (2010).

As for the remainder of the paper, section 2 describes the wok handling motion capture experiment, and Section 3 introduces the feature variables for the motion and uses these variables to characterize the manner in which an expert performs the motion. Then, Section 4 classifies the pieces of advice given by the expert to the learners in the experiment, and Section 5 analyzes the teaching strategy used by the instructor by characterizing and comparing the learners' processes in mastering the motion based on the advice sequence and the manner in which the characteristics of their motion performances change along it. Finally, Sections 6 and 7 provide a discussion and the conclusions of the study.

## 2. Motion capture experiment

### 2.1. Example motion

One of the basic motions for handling a wok (a Chinese frying pan), a back and forth swinging action, is chosen as an example in the experiment because some noticeable improvement in the manner in which the motion is performed can be expected during the period of the experiment. In addition, the characteristics of the motion can be monitored using an optical motion capturing system and technical support is available from a very experienced instructor. The back and forth swinging action involves moving the wok with the left hand so that its contents are stirred and move around a horizontal axis, while at the same time supporting the operation with a ladle in the right hand.

### 2.2. Participants

Three male students of Doshisha University in their early twenties (called Novices A, B, and C) attempt to master the example motion in this experiment. Further, a 44-year-old male professor of Chinese cuisine (called the Expert) from a culinary school is also invited as the instructor of the motion. Before starting the experiment, an explanation of its procedure is provided to all the participants, who then agree to participate in the experiment. They are treated according to the ethical research guidelines of the University.

### 2.3. Procedure

A trial of the motion executed by the Expert is first recorded as a model performance. Then, a series of four trials performed by each Novice is captured. The time length of each trial is around 30 s. Further, some advice is provided to each Novice by the Expert after every trial, and an audio recording of this advice is made. The length of each instruction session is about 60 s. Each Novice is then given sufficient time to practice before starting the next trial. Table 1 summarizes the trials recorded in the experiment.

In this motion capture experiment, the modified Helen-Hayes marker set shown in Fig. 1 is used (Kadaba et al., 1990). The markers are placed on the subject's body, and their XYZ-coordinates are traced at 200 frames per second during each performance using an optical motion capturing system (MAC3D system of Motion Analysis Corporation). Thus, the motion data of each trial are originally in the XYZ-coordinates of the markers recorded at 5 ms intervals. They are then translated into joint angle data with 34 degrees of freedom using SIMM (software for interactive musculoskeletal modeling) from MusculoGraphics Inc. (Delp et al., 1990; Delp and Loan, 1995; Delp and Loan, 2000; Delp et al., 2007). Finally, any possible trend in the joint angle data is eliminated by taking the first order difference. This translates the data into joint angular velocities.

## 3. Motion characterization

### 3.1. Feature variables of motion

The motion data obtained above are in the form of a time series of 34 joint angular velocities and hence have too many degrees of freedom to interpret the characteristics of the corresponding performance of the motion. An earlier work (Yamada and Mizuyama, 2008) applied principal component analysis to the data and confirmed that the major part of the motion data can be described as cyclic movements of the left and right arms. However, because the principal components are composite variables, it is not easy to clearly understand the manner in which the characteristics of the

**Table 1**
Recorded motion trials.

| | 1st trial | 2nd trial | 3rd trial | 4th trial |
|---|---|---|---|---|
| The expert | E1 | – | – | – |
| Novice A | A1 | A2 | A3 | A4 |
| Novice B | B1 | B2 | B3 | B4 |
| Novice C | C1 | C2 | C3 | C4 |