Verbalization of problem solving processes in unaided object assembly

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Introduction

Imagine buying a dollhouse for your niece at a garage sale, and what you get is a set of wooden pieces and a picture of the house, but no instruction manual. How do you solve the problem of assembling the pieces to build the house? What you are facing is a well-defined problem, since you know the goal state and all objects needed to reach the desired state; only the correct sequence of actions is missing.

Newell and Simon (1972) postulate the following general structure when a problem is encountered: *orientation phase*, *construction of the problem space*, and *exploration of the problem space by selecting and applying operators*. During the orientation phase the problem is recognized and the situation is analyzed. This initial analysis is extended by the construction of a detailed representation of the problem (*problem space*) that includes information on the initial state, the operators that can be applied to change this state, and information on how the goal state is defined. The construction may be based on the analysis of the task environment or retrieved from long-term memory. The problem solving process itself is defined as a *search process* through the problem space. In the search process the problem solver applies different methods to create new states and checks repeatedly if those qualify to be the goal state. Palmer (1977:466) considers the following processes crucial to organizing problem parts: *exploratory hypotheses*, *false leads*, *dead ends*, *backtracking*, and *fresh starts*.

Unaided object assembly: an explorative study

In our study we aim to identify the cognitive processes involved in unaided object assembly by examining think-aloud protocols, along with a better understanding of how these processes are expressed in language. Think-aloud protocols are traditionally used to gain insights on cognitive processes involved in problem solving (Ericsson & Simon, 1993), typically focusing on content, i.e., *what* is verbalized. Further insights can be gained from analysis of the language used, i.e. *how* thoughts are verbalized. Roth (1985), for example, showed that unsuccessful problem solvers used more negations, adversative conjunctions, and modals than successful problem solvers. Caron-Pargue and Caron (1991) illustrate how linguistic markers (e.g. lexical choice, connectives) give insight on the problem solver's representation with regard to organization, function, and change.

Design

56 university students (26 male, 30 female; aged 19-42 years, mean age 24 years) participated in this study for course credit or monetary compensation. They were told that they would be given object parts that need to be assembled without a manual. Knowledge of the goal state varied between mention of "a dollhouse", being shown a picture of the assembled dollhouse, and no such information. Here we focus on phenomena common to all three conditions. After the instruction was given, participants entered a room and saw a cardboard box and a triangular piece of wood on a table. The box contained 13 wooden parts. Participants were instructed and reminded to think aloud while solving the task.

Analysis

30 think-aloud protocols were analyzed for current purposes, namely the identification of general problem solving processes and their expression in language.

First, the general structure of the problem solving process was identified by a detailed content analysis of 11 protocols. With regard to the *search process*, the process categories as proposed by Palmer (1977) were identified and extended. These categories were linguistically analyzed in 18 protocols with regard to verb classes (cf. Halliday & Matthiessen, 1999), conjunctions, negations and affirmations, and the discourse markers *so* and *okay*. Next, all 30 protocols were annotated according to these categories in order to describe their distribution in more detail, and to identify recurrent sequences of processes.

Results

All protocols showed the general structure of an introductory sequence in which parts of the instruction were repeated or object parts were recognized, and first associations were verbalized. The main body of the protocols consisted of the actual problem solving process. In most protocols the task was concluded by a brief evaluation of the assembled object, or the personal skills in solving the task. Inspired by Palmer's (1977) approach, *hypotheses*, *false leads*, *dead ends*, and *fresh starts* were identified. The content analysis revealed four additional categories, namely *description of mental state*, *perception of object features*, *action* (including plans for action), and *positive evaluation*. Since *false leads* can also be understood as evaluations, this category was renamed *negative evaluation*.

Altogether, 1,405 processes were identified and annotated in the 30 protocols. Of these, *hypotheses* were most frequent (42.5%), and 20.5% were instances of *action*. *Evaluations* were *positive* (9.7%) or *negative* (7.8%); these will be combined in the following.

The chain *hypothesis–evaluation* was found in 42.5% of all possible process chains starting with *hypothesis*, and *hypothesis–action* in 41.5%. For the category *action,* the chain *action–hypothesis* was most frequent (56.1%). Those three sequences occurred in 26 out of 30 protocols. The sequence *action–evaluation* accounted for 35.0% of all possible chains starting with *action*. *Positive evaluation–hypothesis* occurred in 46.3% of all chains starting with a positive evaluation. These two chains were identified in 23 and 24 protocols, respectively. *Negative evaluation* led to a *hypothesis* in 61.3% of cases; however, this chain occurred in only 11 protocols. The combination of these sequences in the four-process-cycle *hypothesis-action-evaluation-hypothesis* was identified in nine protocols.

Based on a detailed analysis of 18 protocols the following linguistic markers were identified. The category *hypothesis* was characterized by frequent occurrences of verbs of 'being and having' (62.2% of all such verbs belonged to the category *hypothesis*), as well as verbs denoting mental processes (44.1%), e.g. *think* or *believe*. Almost half (47.1%) of the utterances in this category were connected by conjunctions; mainly introducing reasons using *because* (41.1%). Further re-occurring markers of *hypotheses* were short phrases expressing the mental state (*I think*) or mental activities (*I'm asking myself*) of the problem solver. The category *action* was characterized by verbs of 'doing and happening', such as *put* or *assemble* (66.1%). Here, the connectives *and* and *because* occurred in 25.7% of cases. The discourse markers *so* and *okay* were identified in 52.0% of all utterances classified as *positive evaluation*, with *so* (79.6%) more frequent than *okay*. Furthermore, this category contained 75.0% of all affirmative words, such as *right* or *super*. Most expressions classified as affirmation or negations were found in the category *negative evaluation,* with 72.3% of all utterances containing such an expression. Almost all of those occurrences were negations, such as *nee* (98,5%). On the other hand, 31.9% of all negations occurred in the category *hypothesis*.

Discussion

The following picture emerges when comparing the problem solving processes identified in our protocols to those proposed in the literature. Content analysis of the introductory sequence of the protocols revealed that it contains the *orientation phase* and the *construction of the problem space* as described by Newell and Simon (1972) because participants were found to recall instruction details and start exploring the task environment. Schoenfeld (1985) also identified *read* and *explore* as the episodes in which a problem solver engages first. The main body of the protocols included the categories *hypothesize* and *action* that correspond to the processes of selection and application of operators respectively. *Hypotheses* represent verbalizations of possible states, such as concepts and object configurations. The reasoning process about these possible states is illustrated by the frequent occurrence of *because* in this category. The continuous evaluation of newly derived states is expressed in the categories *positive* and *negative evaluation*. As *so* conveys a meaning of result (Schiffrin, 1988) *positive evaluations* can be interpreted as signals for reaching sub-goals. This stands in contrast to negations, so-called markers of denial, which signal the rejection of an idea and may result in a complete reorganization of the representation (Caron & Caron-Pargue, 1991:32). The finding that *evaluations* are frequently followed by a new *hypothesis* supports these interpretations. Both findings illustrate the importance of the control process.

Empirical research revealed the difficulty of identifying longer process sequences since, unlike in theoretical models, the processes tend to occur in various sequential orders (e.g. Wedman et al., 1996). In our study, we found that *actions* frequently occurred with *hypotheses* and *evaluations*. A combination of these processes, namely *hypothesis-action-evaluation-hypothesis*, was identified in one-third of all protocols. This sequence represents the theoretically assumed progression of problem solving processes that is repeated until the goal state is reached.

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