Bottom-Up Learning of Feedback in a Categorization Task

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***Abstract*—We designed a laboratory study to investigate the influence of social interaction on category learning. The objective in the present study is to examine what kind of teaching behavior can improve an agent's learning of categories. In a computer-based study participants learned four categories for sixteen objects which appear on a computer screen. The objects' categories determine what kind of manipulation is to be done on the objects. Five tutors and twenty participants were recruited to participate. For the study the tutors were placed in front of a computer in one room whereas the learners were in another room. The learners' task was to manipulate the objects appropriately through the instructions they received from the tutor on their screens via six symbols. These six symbols were the only way for the tutor to communicate with the learner. We call this a bottom-up learning as it relies entirely on the perception of the tutors' symbols without any prior knowledge of their meaning. The focus in the present study is not on the ability by the learner to acquire knowledge of the categories but on the types of instructions that the tutor gave during the trials and the effects of the feedback given to the learner. Therefore, the feedback given by the tutors via the symbols was classified and quantified.**

I. Introduction

Humans acquire knowledge about the world in two ways. They either use their perception and actions to explore the world and learn about it or they learn from others. The importance of learning from others is clearly visible in human infants who learn about the world from their parents before they can actually move around to explore their larger environments. Building on the oberservation that social interaction is important for human cognition, we chose to study the influence of social interaction, in its meaning of two agents solving a common task [7], on category learning on an abstract level.

The aims of this study are to examine how tutoring influences category acquisition and, more specifically, how different types of feedback affect learning. We aimed at creating a bottom-up learning scenario in which the feedback itself also needs to be learned. The symbols have no predetermined meaning and the learner cannot rely on any previous knowledge about the symbols.

In line with Galantucci and Sebanz [1] we hypothesized that symbolic feedback should improve the performance of individuals in the task. We were also interested to see how the participants would use a rather simplistic choice of symbols to generate useful feedback that increases the performance of a learner.

To target these objectives, we adopted a controlled scenario similar to that introduced in [2] and described in section III. The new study involves two type of agents:

1) *Tutors*, who learn to master the task during an initial phase and then support the learners during a second phase.
2) *Learners*, facing the same learning task as in [2], who however could use the tutors' guidance instead of relying solely on their own exploration.

The structure of the paper is as follows: First, we look at the previous experiments which the current laboratory study is based upon as well as the related work in experimental semiotics. Then the methodology of the study will be presented. The findings are presented in the following section. The discussion of results is followed by the conclusion.

II. Background and Related Work

Category learning is an important skill of human cognition [3], [4], [5]. Morlino et al. designed a study to test differences and similarities between artificial cognitive agents and humans [2]. In a computer-based task participants, both artificial and human, had to learn about the affordances of objects shown on the screen. They showed how different categories were learned on the basis of object properties. However the human way of learning is often based on social interaction which is also based on shared symbols. Cangelosi and Harnard showed in simulation that learning from symbols is advantageous compared to learning which is solely based on perception and action (i.e. the agent's own exploration of the world) [6].

The rather young field of experimental semiotics tries to develop methods in which joint action is investigated in controlled studies in the laboratory. Here one can see the emergence of communication systems with language like structures which prove to be effective for a task that participants are given by the experimenter (such as finding each other in a maze [9]). Galantucci showed how in a laboratory set up participants developed a complex communication system in task oriented dialogues without using language but only using a device which displayed symbols on screen which were subject to the same constraints as human speech (e.g. rapid fading) [10]. Kirby et al. showed how a system of symbols self-organized during a categorization task based on an alien world experiment [11]. These kinds of studies allow a close look at the principles underlying human verbal and non-verbal interaction in a way which is not possible by looking at natural interactions. Galantucci and Steels have already shown that the results obtained through these types of experiments are similar to the emergence of communication systems in robotic agents [12]. Therefore, we decided to add a social layer to the experiments of Morlino et al. in order of finding out whether interaction improves agents' performance in a category learning task. Here the focus lies on the laboratory study with human participants. To our best knowledge, none of the studies within the paradigm of experimental semiotics has focused on teaching scenarios but have rather focused on objects and their properties or giving directions in task oriented interactions.

Adult-child interactions are the main inspiration for the present study. In the motionese data set (see [13], [14]) adults explain objects such as cups, a bell, a box, toys and a slat shaker to a child. Especially, they explain *what can be done with the objects* and *where they need to be placed*, following the instructions given to them by an experimenter. The adult caregivers use a number of linguistic cues, attentional cues and social cues to manage the child's attention in order for the child to be able to grasp the structure of the action which accompanies such tutoring situations [15]. The action learning, object learning and language learning required for the knowledge acquisition process develop concurrently [16]. We see a similarity to the tasks presented in [13], [14] as the learner needs to understand how to manipulate objects and where they need to be placed. Therefore, our alien world scenario (see III) reproduces, on an abstract level, the task which the children are presented with.

In our scenario we tried to recreate a situation in which one interaction partner (the tutor) has prior knowledge analoguous to the parents in child development and the learner needs to pay attention to the tutor's feedback in order of completing the task at hand. Using an unknown communication system also recreates the child's condition as the child has to learn the meanings of the caregiver's cues while completing the learning task.

Similar processes may also benefit the development of technical systems which should be able to do bottom-up feedback learning from tutoring situations. For this purpose the system would need a cognitive architecture which is able to reduce the costs of learning by supplementing its exploration of the world with capabilities for interpreting the signals other intelligent agents with suitable knowledge offer them.

Within the framework of developmental robotics, researchers try to find methods which help robotic agents learn from human tutors [8]. For this purpose the structure of tutoring needs to be better understood.

III. Method

We carried out a series of laboratory studies on category and action development in a social context. More specifically, we investigated how tutoring (with particular reference to symbolic feedback provided during situated interaction) influences category and action acquisition.

A. Participants

The participants, recruited among students and staff at the campus of Bielefeld University, were divided into tutors and learners. They registered to be participants beforehand. Overall, five tutors and twenty learners took part in the study. The age range of tutors was between 22 and 29 and their average age was 25.6 years. Whereas the age range of learners was between 20 and 38 and their average age was 27.3 years. The twenty learners were assigned to the five tutors in equal numbers. This means that each tutor got to instruct four participants.

All participants signed an informed consent form before beginning their task. After having completed their respective task participants received a monetary compensation.

B. Stimuli

For the purpose of the present study the software application created for the experiments reported by Morlino et al. [2] was altered in order to allow a tutor to send signals to the learner by using buttons on the keyboard of his computer to activate buttons at the bottom of the screen which both participants would see. The task for the learner remained unaltered. Their task was to manipulate objects which followed the mouse cursor which the learner controlled via the mouse connected to their computer.

The training scenario consists of learning to master a manipulation task in which two-dimensional objects varying with respect to features such as shape, color, and weight and grouped in unknown categories had to be manipulated in unknown ways.

The objects are shown in Figure 1. The objects can be either circles or squares, red or green, light or heavy, blinking or not blinking. All 16 objects will have one of two properties from a set of these four possible properties.

The important thing to note is that the categories are comprised

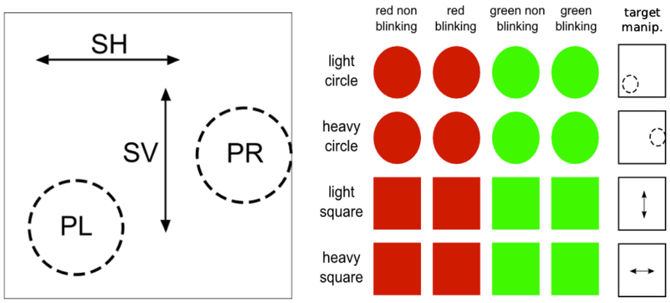

Fig. 1. The alien world scenario consists of sixteen objects which appear on screen during the trial within an area in which they can be moved by moving the mouse cursor. The objects are each part of one of four categories with an associated target manipulation. Although, each object has four properties only two of them determine the category to which it belongs. The left hand side shows the target manipulations which the learner has to perform SV stands for shake vertically, SH stands for shake horizontally, PL stands for place left and PR stands for place right. The right hand side shows the sixteen objects in the alien world scenario with the rows being the categories and the columns being the objects which belong to those. The last column on the right for each row shows which target manipulation was associated with each category.

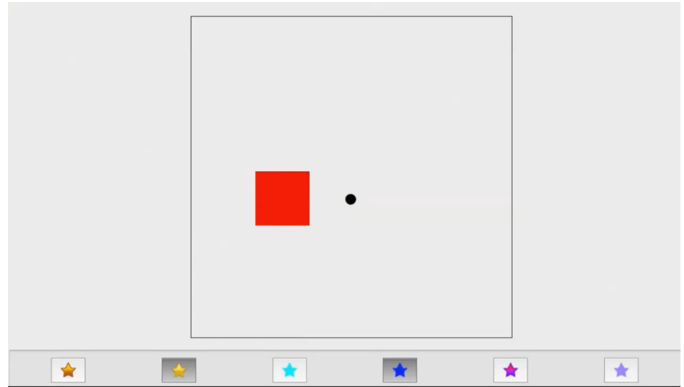

Fig. 2. A screenshot of the alien world scenario as it was seen both by the tutor and the learner. The second and the fourth buttons are pressed by the tutor in this example, while the other buttons are released (i.e. have not been pressed by the tutor and are therefore not activated). The object follows the mouse cursor which the learner has to move in order of manipulating the objects.

of four objects each. This means that not all properties are relevant for a category. More specifically, shape and weight were relevant while color and blinking were not. Each category is associated with a particular target manipulation:

1) Light circles, regardless of their color or the blinking properties, need to be *placed* in the bottom left corner.
2) Heavy circles, regardless of their color or blinking properties, need to be *placed* on the right hand side.
3) Light squares, regardless of their color or blinking properties, need to be *shaken* vertically.
4) Heavy squares, regardless of their color or blinking properties, need to be *shaken* horizontally.

Therefore, each tutor had to memorize four object categories which are associated with four target manipulations. These target manipulations fall into two broader categories - *place* and *shake*. The objects together with the grey screen on which they appeared made up the *alien world* which was presented to participants in the present study as well as those who participated in the experiments reported in [2].

Overall, there were 16 objects shown to each learner four times which amounts to a total of 64 trials overall. Each item was on the screen for 12 seconds. At the end of each trial a score was shown for three seconds. This made the main phase of the study 16 minutes long for each participant (15 seconds per object times 64 items). The status of the buttons (pressed or released), the position of the mouse and the position of the object was recorded at 25 Hz, i.e. every 40 milliseconds. The buttons could either be pressed or released (not pressed). This information was recorded as 1 or 0 in the data file. After the main phase of the study for a learner was completed, the tutor and the learner were interviewed together on what the buttons were meant to indicate and what the learner thought each button was meant to represent.

C. Procedure

The study was conducted in two separate but adjacent laboratory rooms. First the tutor arrived. They received their training for the alien world scenario (see Figure 1) until they were able to regularly and consistently display optimal performance on all objects.
The experimenter explained the task before the tutor started exploring the alien world scenario and learning the categories of objects and the target manipulations. They were then asked to indicate once they reached a certain level of proficiency with the object categories. To speed up and facilitate tutor learning, the tutors were allowed to see the current achieved score while they were manipulating the objects. The goal was to reach a point were the tutor regularly and stably reached 100 % for each of the objects. This was taken as an indicator that the categories have been learned successfully and that the tutor was in the position to effectively tutor the learning agents. After that the learners were brought into the other room, one at a time. The learners were given instructions as to what their task was. They were told to manipulate the objects on the screen using the mouse and that there were right and wrong ways of handling the objects. The participants were also informed that a tutor was going to help them by pressing/releasing the buttons shown at the bottom of their screen (see Figure 2).
Both participants, the tutor and the learner, saw the same view of the scene (see Figure 2). The learner manipulated the objects and had to either *place* or *shake* them. The tutor manipulated the six buttons to help the learner. There were no instructions as to what the buttons meant. So each tutor was left free to decide how to use the buttons. The manipulation of the buttons constituted the only way for the tutor to communicate/help the learner and the observation of the buttons state constituted the only way for the learner to receive feedback from the tutor.

IV. RESULTS

Despite the complexity of the task and the limited time – the training section only lasted under 30 minutes – an effective tutor/learner interaction was established in most of the cases. The analysis of the way in which buttons were used by the tutors (see Figure 3) reveal two main strategies, often used in combination:

1) using buttons to provide concrete instructions (e.g. one button to elicit a move-up behavior, one button to elicit a move down behavior etc.) or iconic instructions (e.g. alternating the press of two buttons, used to elicit move-left and move-right behavior to elicit an horizontal oscillatory behavior);
2) using buttons to provide positive and/or negative feedback.

Only part of the signals were correctly understood by the learners, other were misinterpreted or simply ignored (see Figure 4). However the signal played a functional role, as is demonstrated by the fact that learners who payed more attention to them (i.e. that ignored less signals) achieved significantly better performance.

Overall, these exploratory experiments demonstrate the possibility to study the dynamics of complex learning processes involving categorization and action development in an individual and social context.

Moreover these exploratory experiments also provide hints at how learning process occurring in artificial agents could be facilitated through simple tutoring mechanisms.

There are three types of results: a) the actual 'meanings' that emerged from the use of the buttons, b) the strategies different tutors used to help the learners, and c) the effects of the feedback on the learners' performance.

A. The meanings of the buttons

The six buttons were used differently not only from tutor to tutor but the tutors regularly changed their strategy from one learner to another.

Overall, the meanings of the six buttons can be classified as belonging to one of five types:

1) positive feedback
2) negative feedback
3) concrete instructions (e.g. directions)
4) unclear (e.g. buttons pressed accidentally)
5) others (e.g. this type of feedback mainly captures 'attention getters')

The most commonly used types of feedback were positive feedback, negative feedback and concrete instructions.

Notable is also what the tutors chose not to communicate using the buttons. None of the tutors used the buttons to actually indicate the category of the object displayed or a single button to indicate whether an object needed to be *placed* or *shaken*. Instead actions were symbolized by a combination of buttons as discussed in section V. The meanings for the learner can be analyzed in a pragmatic fashion. There are three types of degrees of understanding:

	Positive	Negative	Concrete	Other	Unclear
Strategy 1			x		
Strategy 2	x	x			
Strategy 3	x		x		
Strategy 4	x	x	x		
Strategy 5	x	x	x	x	
Strategy 6	x	x			x

TABLE I
A SUMMARY OF THE TEACHING STRATEGIES EMPLOYED BY THE TUTORS.

1) The tutors instructions were understood if the learners interpretation and the intended meaning matched.
2) The symbols were sometimes misinterpreted which meant that the learners for example understood a concrete instruction as a positive reinforcement.
3) There were also symbols that were simply ignored by the learner (either unintentionally ignored or because they could not deduce their meaning).

Overall, not every signal from the tutor to the learner could be interpreted.

B. Tutoring strategies

The tutors' behavior results to be highly variable. Such variability was observed not only between tutors but also within the behavior exhibited by the same tutor with different learners. However in twenty runs of the experiment six different strategies emerged with several being more frequently adopted than others. The strategies are summarized in Table I.

There was a general tendency for tutors to simplify their strategy from trial to trial. Two tutors out of five did not change their strategy at all, though.

Tutor A for example started with one of the most common strategies, the combination of positive feedback, negative feedback and concrete instructions (Strategy 4 in Table I), but shifted to a concrete instruction strategy with the last learner (Strategy 1 in Table I).

Tutor B used two buttons for indicating positive and negative feedback and one button to indicate that he/she did not know what to do (an information that, of course, could not help the learner).

Tutor C used positive feedback, negative feedback and concrete instructions which overall became the most commonly adopted strategy.

Tutor D converged on the same strategy which they used by the second learner's trial after having used positive and negative feedback only with the first learner.

Tutor E showed a lot of variation in the use of the buttons. However the most interesting strategy was combining positive feedback with concrete instructions. Negative feedback was only given to one learner by this tutor. Another symbol was introduced, however, it proved ineffective and the tutor later

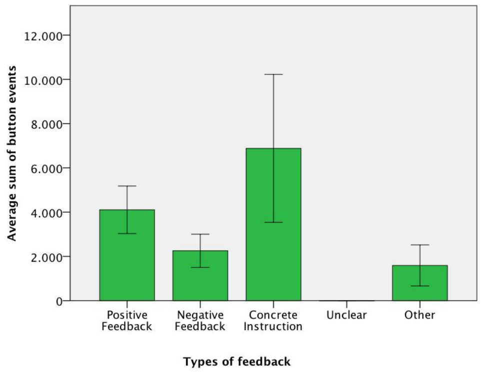

Fig. 3. Number of buttons press/release events for buttons conveying different types of feedback. Data averaged for the four tutors.

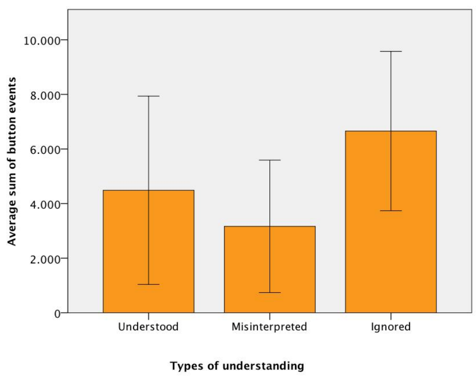

Fig. 4. Distribution of feedback signals that were understood, misunderstood, and ignored by learners. Data averaged across all learners.

stated that he did not really know what it was supposed to signify apart from making the learner do anything at all (this is one of the few examples of an attention getter being used which would be more frequent in child-directed speech).
Therefore, the most commonly adopted strategy showed that three types of instruction are needed for the task at hand: concrete instructions, positive and negative feedback. The most minimalistic strategies would just rely on positive and negative feedback and did not try to indicate the directions for moving the objects. A final uncommon tutoring strategy simply relied on using the buttons to give directions and then give positive feedback when appropriate. These are the three most effective tutoring strategies discovered and used by the tutors.

C. The effects of the feedback on the learners' performance

Figure 3 shows the number of buttons press/release events for buttons conveying different types of feedback averaged for the four tutors. The categorization of feedback types was performed manually on the basis of the tutor and learner interview. Concrete instructions are given significantly more than negative feedback ($t(19)$ = 2.77, $p < .05$). Negative feedback is also given significantly less than positive feedback

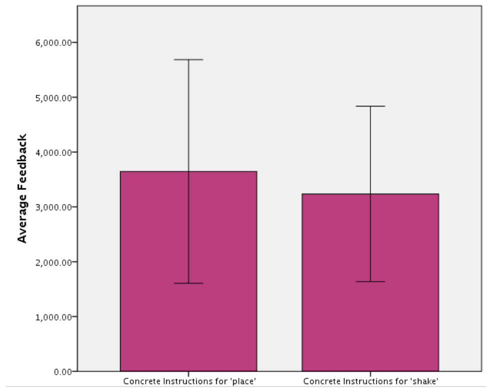

Fig. 5. Number of buttons press/release events for buttons conveying concrete instructions across the two action types, place and shake. Data averaged for the four tutors.

($t(19)$ = 3.26 , p = .004). All other interactions were not significant.
The types of feedback were also correlated with the task success. We observed a significant negative correlation between negative feedback and task success (r = -0.561, n = 20, $p < .05$) suggesting that participants who received more negative feedback performed worse in the task. All other interactions between the success score and the feedback types showed no significant results.
Figure 4 shows the distribution of feedback that was correctly understood, misunderstood, and ignored by learners on average. As can be seen, a large amount of feedback was ignored. There is a significant negative correlation between ignored symbols (those which were either not attended to by the learner or which were not understood) and task success score (r = -0.449, n = 20, p < .05) suggesting that learners who did not pay attention to the symbols performed worse and therefore feedback had a positive effect on the learners' task performance.
Looking closer at one feedback category, one notices that the concrete instructions did not differ significantly with regard to the *place* and *shake* actions to be performed by the learner. The tutors pressed the buttons equally frequent on average for both manipulation types. This is shown in Figure 5.
We found a significant strong correlation for the two action types (r = 0.684, n = 20, $p = .001$). This is interesting as one action is semantically rather about *where* an object needs to be moved (*place*) whereas the other is about *how* an object needs to be moved (*shake*).

V. Discussion

The tutors seem to use three main types of instruction in order to help the learner: positive feedback, negative feedback, and specific instructions. Instructions can be concrete or iconic. A common example of concrete instructions is constituted by the use of four different buttons (that assume the meaning of 'up', 'down', 'left' and 'right') to inform the learning agents on how an object-to-be-placed should be moved toward the appropriate location. A common example of iconic instructions is constituted by the rapid alternation of two buttons (that assume the meaning of 'left' and 'right') to indicate the need to display an horizontal oscillatory movement.

Interestingly using buttons to convey positive and/or negative feedback leads to a form of trial and error learning that is less informative with respect to the form of learning based on specific instructions. The trial and error learning modality, on the other hand, forces the learning agents toward the development of an ability to handle the objects correctly also without the help of the tutor. The alternative strategy based on concrete instructions can lead to a faster learning process but, on the other hand, might produce agents that strongly dependent on the tutor's help. The fact that the two tutoring strategies produce similar effects on the learners could therefore be explained with the relative advantages and drawbacks of the two strategies.

Another interesting result is constituted by the fact that 4 out of 5 tutors used negative feedback which had the smallest effect on learners' performance. The interpretation of this result is puzzling since one can either hypothesize that negative feedback is an ineffective tutoring strategy or that it is elicited by poor learning performance. Still another possible explanation consists of hypothesizing that the negative feedback becomes beneficial only in the long run.

A third interesting aspect concerns the online establishment of communicative conventions between the tutor and the learning agents. Although, communication does not always succeed (the majority of the signals are ignored or not comprehended) the rapidity with which communicative conventions are established is remarkable. The established communication systems also play a clear function role. Indeed, although, the effects of concrete instruction and positive feedback could not be directly shown, the effect of ignored feedback showed a significant negative correlation.

A final interesting point concerns the ease with which tutors were able to find symbolic representations for the manipulations. They used the buttons representing the actions which the learners had to perform with the objects with similar frequencies for the *place* and *shake* actions. This is noteworthy as in child language acquisition the expressions which encode *where* something moves (so-called *path* expressions) precede those which encode *how* something moves (so-called *manner* expressions) [17]. One can see that these meanings are not inherently harder to communicate (i.e. symbolize and understand) in our scenario.

VI. Conclusion and Outlook

There were several different ways of tutoring which were used to communicate during the task. Three main types of instruction were found: positive and negative feedback and concrete instructions. There is no difference between the way in which the two different types of action which are to be performed by the learner are communicated by the tutor. What is prominently missing from the feedback categories is any naming of objects or actions or symbols used for the purpose of passing on knowledge about the categories. Instead the tutors aid the learner's own exploration of the scence by giving clues as to what task is to be performed and on what the learner is doing right and what the learner is doing wrong.

The effect of ignored feedback showed a significant negative correlation. Therefore, feedback itself is beneficial if it is understood.

In a follow up study, we will investigate the same task performed by artifical agents. A neural network will explore the scene and receive similar feedback to the human learners. That feedback will be modeled on the mechanisms which were shown by the human tutors in the present study.

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