Impact of Affective and Informative Feedback on Learning in Children before and after a Reattribution Training

An Integrated Approach using Neuroimaging, Educational Research and Modelling

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Theoretical Background

There are many situations where feedback provides essential information needed for performance evaluation and subsequent adaptation. Feedback is thus a major topic in educational, cognitive and neuroscientific research and is of high relevance for every day educational practice. On the one hand, feedback is necessary and can be expected to be particularly supporting in areas were systematic learning is crucial, such as in science education, since it provides the essential information needed for adaptation. On the other hand, it has been shown that feedback can interfere with the learning process and it has been suggested that this is due to the affective component of feedback (Dweck, 1999; Dweck, Legget, 1988). So far, only a few studies have tried to disentangle these two aspects of feedback (Edwards, Pledger, 1990). For example, findings on ways to provide effective feedback are still a matter of controversy. When observing teachers in their everyday classroom practice, several studies showed that the frequency of giving feedback is low, especially when looking at powerful feedback (Bond et al., 2000). There are few studies that have explicitly manipulated the effects of affective feedback. One remediation program which has been successfully employed in schools and aims to change the way one copes with feedback in learning situations, is the reattribution training (Ziegler, Schober 1997, 2001). Ziegler and Schober (2001) showed that this training which aims to change maladaptive attributions improves learning. The overarching aim of the current interdisciplinary approach is to investigate learning strategies and the role of feedback on learning. The project was carried out by four project groups at the University of Oldenburg and the IPN Kiel and covered the areas of cognitive neuroscience, educational research, science education and cognitive modelling (Table 1). The cognitive neuroscience approach provided neural data on feedback processing, which is not accessible by behavioral research alone. The classroom study was carried out with the intention of investigating (a) the role of corrective and affective feedback on learning processes behaviorally; and (b) the students' understanding of rules for basic chemical formulae, the strategies students developed during the learning process, the use of supporting tools and their correlations with personal characteristics, e.g. their beliefs about causalities for success or failure. Finally, cognitive modelling has allowed us to investigate whether a cognitive architecture (Anderson et al., 2004) could be used to model the learners' behaviors in tasks relying on individual strategies.

Tab. 1 Research questions of the four different research areas

Research group	**Research questions**
Research on Learning and Instruction	What kind of effects does an attributional retraining have on the learning process in children under the conditions of corrective and affective components of feedback in learning tasks?
Cognitive Neuroscience	What are the neural correlates of affective components of feedback and are these modulated by a reattribution training?
Cognitive Modelling	How do a non-algebraic task domain, modelling paradigms, and multi-dimensional strategy spaces affect the BOLD prediction capabilities of the ACT-R cognitive architecture? Can affective and informative components of feedback be modeled with an ACT-R model, which also predicts behavioral and neural data?
Chemistry Education	How can the acquisition of the chemical formulae be influenced by supporting tools and the development of strategies?

We chose a science learning situation and designed an experimental task where students had to match a chemical formula or model with a respective designation, or vice versa and received different types of feedback. The exact type of task and the feedback provided varied slightly between project groups (see Fig. 1). Our subjects were young high school students (age 10–13 yrs). They were assigned to two groups, one receiving the reattribution training and one receiving normal teaching. All students were measured once before and additionally 15 weeks after the intervention.

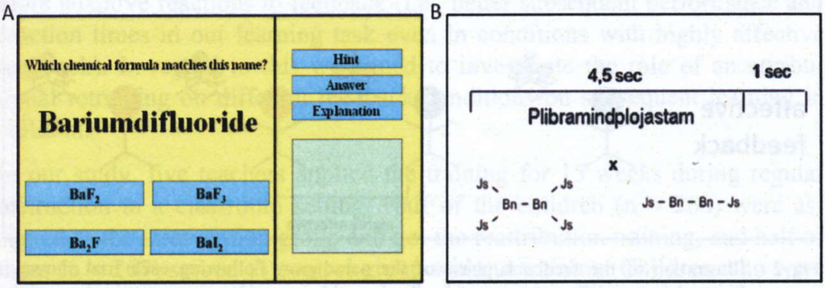

Fig. 1 Illustration of the task of the paradigms
A. Task used by the project groups Learning and Instruction and Chemistry Education. In the chemical formulae paradigm, students got a series of tasks to be solved in a self-paced manner after a short introduction. Within each task a chemical formula and four possible names were presented and the students had to decide which name matches the formula or vice versa. The complexity of the tasks increased gradually, ranging from simple element names (e.g. Lithium – Li) to compounds (e.g. Bariumdichloride – BaCl2). While working on the tasks, the students had the chance to use different supporting tools. Scale and depth of the supporting tools increased, starting with a general hint to focus on a certain aspect or offering an analogy and ending with the proper answer including an explanation. The choice whether and which supporting tools are used was up to the student.
B. Task used by the project groups Cognitive Neurosciences and Cognitive Modelling. The task required rule-based matching of chemical structures (pseudo formulas) with their respective names. Children were acquainted with the rules prior to the first scanning session. They were shown two simultaneously presented chemical pseudo formulae and one name for 4.5 seconds. Within 5.5 seconds, they had to decide via button press which of the formulae matched the presented name. After a variable delay (2–18 sec.), they received the affective feedback (2.5 sec.) shown in Figure 2.

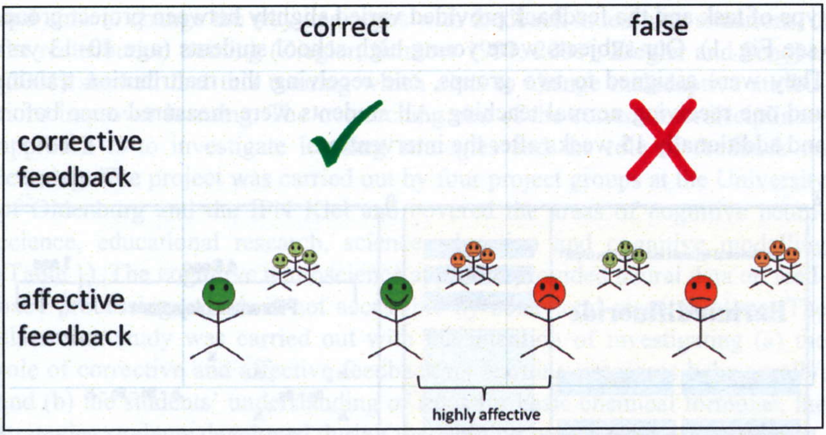

Fig. 2 Illustration of the feedback phase of the paradigms. Following each trial shown in Figure 1A, two different types of feedback could occur. One group received corrective feedback indicating correct or false performance and the other group received corrective feedback that was additionally related to the performance of an alleged peer group. The affective value of this feedback was manipulated within subjects by providing feedback of high affective value (indicating that the performance was better or worse than those of an alleged peer group) or feedback with low affective value (indicating that the performance was similar to that of an alleged peer group). Note that in the Cognitive Neuroscience study only affective feedback was provided after the learning phase shown in Figure 1B.

527 children were tested at three time points with the paradigm depicted in Figure 1A. These children also performed an additional set of psychological tests and questionnaires. Another 30 children were tested with fMRI with the paradigm shown in Figure 1B. This data was also used for the modelling approach aiming at predicting behavioral and neural data on an individual level.

Methods and exemplary results of the four disciplines

Project Group: Research on Learning and Instruction

According to the attribution theory, students are more or less motivated due to their beliefs about causalities of success or failure. With this in mind, the aim of reattribution trainings is to change causal explanations from a lack of ability to a lack of effort and to improve the students' beliefs in the cause of their failures and successes e.g. to promote future motivation. Ziegler and

Schober (1997, 2001) designed attributional retrainings to be applied in everyday classroom situations.

One focus of the current study was to evaluate the effects of such reattribution training in relation to possible reactions to affective and corrective feedback processing. We expected that the reattribution training would lead to more adaptive reactions to feedback (i.e., better subsequent performance and reaction times in our learning task even in conditions with highly affective feedback). In regard to this we aimed to investigate the role of an attributional retraining on different feedback conditions on subsequent learning in children.

In our study, five teachers applied the training for 15 weeks during regular instruction in a classroom setting. Half of the children (n = 260) were assigned to the intervention group and got the reattribution training, and half of them (n = 267) served as control group without training. Children who were not trained continued to receive normal instruction in their classrooms. All children were unaware of the intervention.

Analysis of subsequent learning processes in the learning task suggest that the reattribution training had an effect on the reaction times following different conditions of feedback. Whereas we found no differences in the condition of corrective (correct or false) feedback when comparing the training and control groups, there were significant effects in the highly affective feedback conditions. As expected, children in the training group were significantly faster in the post-test on the following trial when they received the highly affective feedback "you are better than your peers" than before the training ($F(1,177)=4.27$, $p<.05$). In comparison, children in the control group showed no differences in the pre- and in the post-test. The same effect of the training was also evident regarding the reaction times following the highly affective feedback condition "you are worse than your peers" ($F(1, 173)=3.85$, $p\leq.05$). A possible explanation for this effect can be that social comparisons, which are disturbing to the learning process, had lost their importance for the trained children.

Project Group: Cognitive Neuroscience

One of the main goals of the project was to investigate whether the reattribution training, which aims to modulate the way feedback is processed, has an impact on feedback-related brain activity. By modulating the self-relevant affective value of the feedback, we hypothesized that children who had previously participated in the training would show a different recruitment of brain areas known to be involved in affective and self-related processes. As the reattribution training is specifically designed to encourage controllable failure attributions, training effects were mainly expected for the highly affective negative feedback condition.

Fourteen of the 30 participating children received the reattribution training (operated by the project group Research on Learning and Instruction) in between the first and second fMRI session. In the fMRI scanner, all children performed a task requiring rule-based matching of structures with their respective names, receiving high or low affective corrective feedback (see Figure 1B and Figure 2). Data were analysed with a three-way ANOVA model and we mainly focussed on interaction effects.

Group analyses revealed that the reattribution training had a clear effect on behavioural and neural data. Both revealed significant effects for the interaction time (pre-/post-test) x group (trained/not trained) that were confined to the negative feedback condition. Behaviourally, we obtained a significant time x group interaction for accuracy performance: Proportion correct responses in trials after negative feedback in the pre-test did not differ between groups, but were significantly higher in the post-test for the group with training compared to the group without training ($p<.05$). Analyses of the fMRI data, yielded a significant time x group interaction in the right superior temporal cortex, among others, which was due to higher neural activity for the trained group as compared to the group without training in the post-test ($p<.001$, uncorrected; feedback condition "worse than peers").

To our knowledge, this is the first fMRI study demonstrating that emotional-motivational training has a significant influence on negative feedback processing in children. Training effects were obvious in both the behavioural and the neural data. As expected, they were largely confined to the negative feedback condition that we assumed would invoke affective and self-related processes, which then impacted performance in the following trial. In line with this, brain regions shown to distinguish between trained and untrained children in our study have previously been reported to be part of a larger network involved in mentalizing and in processes that bear a relevance to the self (Gallagher, Frith 2003; Schmitz, Johnson 2007). Thus, the results obtained revealed a clear beneficial effect of the reattribution training on performance when children are faced with negative outcome information. We propose that heightened activation of brain areas, known to process self-relevant information, reflect cognitive processes associated with the more controllable failure attributions assumed to underlie this efficient performance.

Project Group: Cognitive Modelling

The Adaptive Control of Thought-Rational (ACT-R) theory (Anderson et al., 2004) is a cognitive architecture, which is used to model simple and complex behavior in various domains. ACT-R can be used to quantify and visualize the relationships among cognitive variables involved in learning and problem solving. In addition, Anderson (2007) postulates a neurophysiological analogy between the cognitive architecture and particular brain regions. These regions are captured within ACT-R by a set of seven modules with specific functions. Assuming the viability of the Anderson's Brain Mapping Hypothesis, the modules predict BOLD signals for the corresponding brain regions, making it possible to compare BOLD signal predictions generated from strategy-specific ACT-R models (Möbus, Lenk, 2009) with BOLD signals obtained from actual fMRI scans.

The ACT-R models had to solve the same problem as the participants in the fMRI experiment (Figure 1B) before the reattribution training. Based on task analysis and interview results (cf. section Chemistry Education), six different major strategies of the participants were modelled using ACT-R. Using Bayesian identification analysis, the problem solving strategies were matched to participants (Möbus et al., 2010). Finally, the strategy-based predictions of BOLD-curves were compared to the obtained fMRI data (cf. section Cognitive Neuroscience). The individual BOLD curves for the trials were aggregated onto a trial template of 10 scans (Carter et al., 2008). Comparing the strategy-dependent module-region correlations between measured and predicted BOLD-curves showed mixed results. For six out of seven modules, correlations between $.73 < r < .95$ were obtained for the best-fitting strategy (Möbus et al., 2011). Negative correlations for the GOAL module possibly point to faulty assumptions with respect to goals and sub-goals in the modelling process. Generally, the modelled strategies differ in their implementation and need further revisions, but the results obtained show that Anderson's Brain Mapping Hypothesis may not be dismissed, but the accuracy of predictions largely depend on modelling paradigms and techniques.

Project Group: Chemistry Education

From the perspective of science education, the project should shed light on the question of how the acquisition of chemical formulae could be optimized. The application and interpretation of chemical formulae is crucial for chemists, but also one of the most difficult and unpopular topics in chemistry education (Schmidt, 1997). The computer-based learning environment aims to trace students' development of strategies over time and how different supporting tools can facilitate the formation or adjustment of strategies.

Although the supporting function was not used frequently (many students stated in interviews that they wanted to solve the problem without extra help), it can be considered very useful to the students, as expected. Average answer probabilities were raised considerably by the use of the different supporting tools. As expected, the increasing amount of information within the supporting tools (from a general hint to an explanation) resulted in increasing answer probabilities.

Within the learning environment, students were asked which strategies (see section Cognitive Modelling) they used to identify the underlying rules of this symbolic language after each of three difficulty levels as well as in additional interviews (N=8). Different strategies were extracted with regard to their responses to the open-ended questions and the interviews. The students expressed 25 indicators to match formulae and names (partially combinations). These were categorized into six levels of strategy quality. Over the course of the learning environment, the strategy quality increased slightly, but significantly (one-way repeated-measures ANOVA, □= .98, F(1.96, 777.9) = 108.54, p < .001, □²= .12). In addition, the quality of the applied strategy correlated with the amount of correct answers (r_s= .22, p < .001). With regard to the supporting tools, the students' learning gains (standardized residuals from pre- to post-test) were not directly predicted by the general use of supporting tools but by the quality of their strategies ($F(5,412)=1.64$, $p < .05$, $R^2 = .06$). The results stress the usefulness of supporting tools but raise questions concerning their target course (supply of content information vs. strategy building) and implementation into classroom practice.

Conclusions

Our interdisciplinary research project provides insights into the brain processes involved in processing the affective content of feedback, its impact on the way that individual students deal with feedback, the strategies students apply to solve highly systematic tasks, such as interpreting chemical formulae and their effect on learning outcomes. The behavioral results provide evidence that only highly affective feedback impacts performance in the following trials. We show compelling evidence that a reattribution training improves performance in highly affective conditions and that these improvements were associated with signal changes in brain areas involved in the processing of affective and self-relevant information, respectively. An interesting approach for cognitive modelling would be the integration of affective information into the ACT-R model. The experimental results obtained in the Chemistry Education Group together with the interviews underline the role of development of elaborated strategies to solve highly systematic tasks, such as interpreting chemical formulae. The experimental feedback provided here was shown to be less important for chemistry learning. Accordingly, the different feedback conditions (see Fig. 2) did not result in different scores.

Further research is needed to bridge the gap between the different disciplines and to develop descriptive and prescriptive models of student learning (Mason, 2009). Nevertheless, the current project illustrates how the complementary use of different approaches (e.g. educational research, neuroimaging and cognitive modelling) seems especially fruitful with regard to the evaluation of interventional studies. While in most cases the differences between disciplinary methods, with each focusing on different levels of analysis, is regarded as problematic, the alignment of these methods here provides a multilayered picture of feedback and its impact on learning processes.

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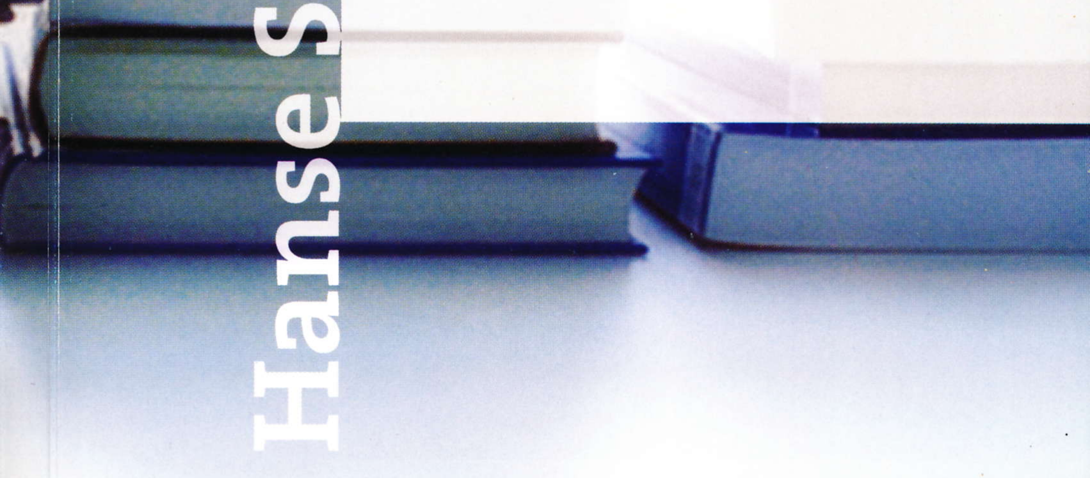

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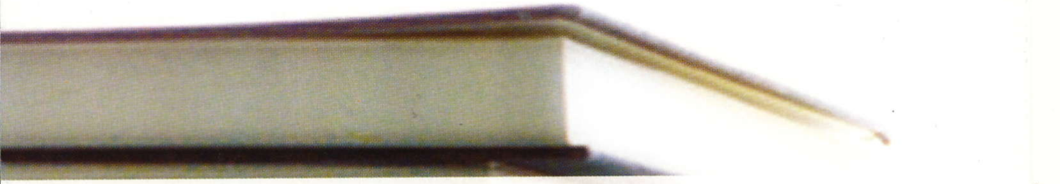

The Cognitive Neurosciences, with the rapidly growing field of brain imaging in particular, have generated a wealth of findings that bear an interesting potential for the field of Learning and Instruction. Notably, the practical use of neuroscientific data for education has been proven to be modest at present and conjoint effort is needed to integrate neuroscientific findings in educational theory. The current reader, as the result of an international and interdisciplinary workshop at the Institute for Advanced Study in Delmenhorst, aims to provide an insight into the wide diversity of the Educational Neurosciences. It combines recent empirical findings from researchers highly interested in an interdisciplinary exchange at the intersection of the Cognitive Neurosciences, Educational Research, and Cognitive Modeling. The inclusion of the Cognitive Modeling research constitutes a fruitful widening of the field, providing valuable tools for representing and testing cognitive models relevant for both the Educational Sciences and the Cognitive Neurosciences.

Ergebnisse der Kognitiven Neurowissenschaften, insbesondere der funktionellen Bildgebung des Gehirns, haben Erkenntnisse hervorgebracht, die ein interessantes Potenzial für die Lehr- und Lernforschung bergen. Der praktische Nutzen dieser Erkenntnisse ist jedoch gegenwärtig eher begrenzt und für die Integration neurowissenschaftlicher Befunde in die pädagogische Theorie und Praxis bedarf es gemeinsamer Anstrengungen mehrerer Disziplinen. Vorliegendes Buch, das aus einem internationalen und interdisziplinären Workshop am Hanse-Wissenschaftskolleg in Delmenhorst hervorgegangen ist, gibt einen Einblick in die Breite und Vielfalt des Forschungsfeldes »Neurowissenschaften und Lehr- und Lernforschung«. Es vereint neuere empirische Befunde von Wissenschaftlerinnen und Wissenschaftlern, die an einem interdisziplinären Austausch an der Schnittstelle zwischen Kognitiven Neurowissenschaften, Lehr- und Lernforschung und Kognitiver Modellierung interessiert sind. Die Einbeziehung der Kognitiven Modellierung stellt eine fruchtbare Erweiterung des Forschungsfeldes dar. Modellierungsansätze können wertvolle Instrumente für die Repräsentation und Testung kognitiver Modelle bereitstellen, die sowohl für die Lehr- und Lernforschung als auch für die Kognitiven Neurowissenschaften relevant sind.

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