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Motivation and metacognition when learning a complex system

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Our cognitive-motivational process model (Vollmeyer & Rheinberg, 1998) assumes that motivational factors (i.e., mastery confidence, incompetence fear, interest, and challenge) affect performance via mediators. Previous studies (Vollmeyer, Rollett, & Rheinberg, 1997) found that strategy systematicity and motivational state during learning mediate the impact of initial motivation on the learning of a complex system. Potential mediators could be other cognitive (e.g., hypothesis testing) and metacognitive aspects, in that more motivated learners (high mastery confidence, low incompetence fear, high interest) analyse more deeply. Verbal protocols from 44 students who learnt to control a complex dynamic system were collected. We measured their initial motivation (on the four factors specified), then during learning we assessed their strategy systematicity and motivational state. Additionally, we analysed the verbal protocols to obtain indicators of learners' cognitive and metacognitive processes. Performance measures were levels of knowledge acquisition and application. The cognitive-motivational process model was replicated. Qualitative cognitive aspects were added as mediators, however, the results for metacognition were problematic, partly because participants gave relatively few clearly expressed metacognitive statements.

Motivation, metacognition, and learning

When trying to understand a text, a mathematical problem, or a new computer game, many different processes are involved. Not only are cognitive processes important, so are metacognitive, motivational, and emotional processes. The aim of our research is to disentangle these different processes and to show how it is possible to simultaneously measure each of these processes. Whereas researchers have mainly studied a single process at a time, recently some have tried to address how these processes may interact: for example, Boekaerts's (1996) work on *self-regulated learning*, Efklides, Papadaki, Papantoniou, and Kiosseoglou's (1997) study on *metacognitive experience*, and our own *cognitive-motivational*

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model (Vollmeyer & Rheinberg, 1998). The broadest of these concepts is metacognitive experience as defined by Flavell (1979). It includes all conscious emotional and cognitive feelings which arise while undertaking cognitive activities. These could be, for example, the feeling that it is impossible to understand the task, or the feeling that one is close to the goal. However, the term metacognition does not embrace just metacognitive experience, but overlaps with the concept of motivation. To emphasise that metacognition has a broad meaning, Weinert (1984, p. 17) showed that variables used to measure both metacognition and motivation are sometimes defined and operationalised the same way (e.g., evaluation of task difficulty, or evaluation of learning results).

How does our own cognitive-motivational model relate to metacognitive experience? In our model we assumed that initial motivation – consisting of task-specific *mastery confidence*, *incompetence fear*, *challenge*, and *interest* – helped knowledge acquisition via two mediating variables: *strategy systematicity* and *motivational state* during learning. Whereas strategy systematicity is a cognitive process variable indicating how systematically participants explore the material, motivational state monitors aspects of their motivational process such as how much fun participants have during the learning task, and their confidence in finding the correct solution. This confidence relates to what participants feel during learning, and is part of what has been studied under the label metacognitive experience. Previous empirical studies (Vollmeyer, Rollett, & Rheinberg, 1997, 1998) showed that participants who were more confident and had less fear chose more systematic strategies, and had a more positive motivational state (i.e., had more fun and were more confident during learning). Both of these mediator variables led to more knowledge acquisition. When participants had to apply their acquired knowledge, again the motivational state was associated with higher performance.

The two mediating variables – strategy systematicity and motivational state – allowed us to coherently explain the learning process. In particular, we could show that motivational processes affected cognitive processes, and that cognitive processes themselves influenced the motivational state during learning. In our previous studies we have used only strategy systematicity to access learners' cognitive processes. Under strategy systematicity we understand how well-directed learners explore a task. However, strategy systematicity is only a weak measure of specific cognitive processes because other factors, such as motivation, ability, or simple luck may influence which strategy is chosen. In particular, to analyse the learning process we need to take into account that different learners can represent the task in different ways, that is, they may have different models of the task (Burns & Vollmeyer, 1997). Their model will influence the cognitive aspects of the learning process, for example, what sorts of hypotheses they form and test. The model will also influence metacognitive aspects of learning. For example, if the task is evaluated as unfamiliar then a different plan will be necessary than for a familiar task.

To measure such *cognitive aspects*, we examined people's hypothesis testing, including their expectations based on their model of the task. Previously, we have used strategy systematicity as an indirect measure of which hypotheses were tested. In this study, we wanted to have direct indicators for what kind of hypotheses participants tested. Depending on these hypotheses, participants should analyse the results in different ways. When participants have to apply their knowledge, they also have to decide on a strategy. Those who have more knowledge should choose more effective strategies. In a study, Vollmeyer and Burns (1995) used the thinking-aloud technique (Ericsson & Simon, 1993), and found evidence that when learners had detailed hypotheses their knowledge acquisition was superior. Therefore, this technique was used in the following experiment.

The second set of variables we wanted to add to our model was *metacognition*. Especially in difficult and complex tasks such as ours, it should be an advantage not only to use one's cognitive abilities but also to use abilities that have been studied under the topic of metacognition. To operationalise metacognition we followed Simon's (1996) idea, that metacognition is mainly used for executive control (i.e., behaviour, strategy, or program that marshals and controls cognitive resources for performance of a task, see Simon, 1979, p. 42). An important function of executive control pointed out by Simon is planning, a metacognitive aspect of problem solving emphasised by Davidson, Deuser, and Sternberg (1994). Therefore, when analysing the verbal protocols generated by the thinking-aloud technique, we categorised remarks indicating that participants planned their learning as metacognition.

Another interesting question we explored was which emotions do participants experience while doing our learning task and whether these emotions are expressed well enough to be consistently revealed in verbal protocols. The study of emotions during learning is important, as it has been found that people's mood can affect learning though the effects may vary with the task (for a summary, see Bless, 1997). However, emotions have not been studied using extended complex tasks as emotions tend to be short lasting (Abele, 1995). Therefore, we examined the verbal protocols for emotional remarks, especially those showing reactions to success and failure. If this method proves reliable and we find sufficient volume of emotional remarks, this would enable us to use the data to test hypotheses about emotions and learning.

Therefore, the aim of the following study was to extend and elaborate our cognitive-motivational model. More direct measures of cognitive aspects of learning should enable us to explain what leads to systematic strategies. People producing more detailed hypotheses should use more systematic strategies, which in turn should help learners to analyse the results in a more effective way. Metacognitive aspects were expected to work in parallel with the cognitive ones, as both have their origin in participants' model of the task: Those who have a clearer understanding of what the task is about should report more cognitive and metacognitive thoughts in their protocols. In addition, this study allowed us to replicate our cognitive-motivational process model, in which initial motivation affects learning via motivational and cognitive mediators.

Our learning task: The biology-lab

As in Vollmeyer, Burns, and Holyoak (1996) and Vollmeyer et al. (1997, 1998), we used the system biology-lab. It is a computer-driven system that was constructed with the shell DYNAMIS (Funke, 1991). The cover story we told our participants was that they were in a lab in which the effects of three medicines (A, B, C) on three substances found in the body (Thyroxin, Histamine, Serotonin) were to be tested. The structure of the system, illustrated in Figure 1, was such that one output was relatively simple to manipulate because it was influenced by only one input (Medicine A–>Serotonin). The other two outputs were more complex, because each was influenced by two factors. One output (Thyroxin) was affected by two inputs, and the other (Histamine) is affected by a decay factor (marked as a circle connected to the output) in addition to a single input variable. The decay factor was implemented by subtracting a percentage of the output's previous value on each trial. Decay was a dynamic aspect of the system, because it yielded state changes even if there was no input (i.e., all inputs were set to zero). The system was thus complex in that it involved multiple input variables that had to be manipulated in order to control multiple output variables, and dynamic in that the state of the system changed as a joint function of external inputs and internal decay.

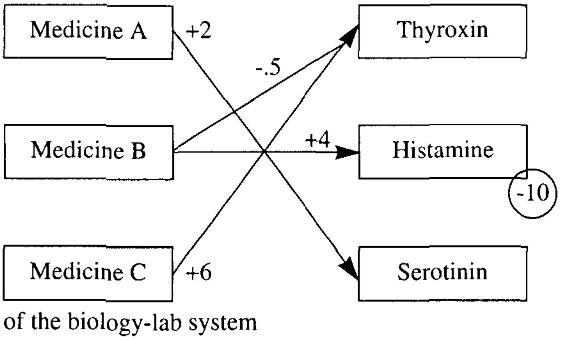

Figure 1. Structure of the biology-lab system

This system can be used for studying two phases: first, participants have to acquire knowledge, that is how the input variables are connected to the output variables (learning phase); second, participants have to apply their knowledge in that they have to reach goal values for each output variable (application phase). For each phase, we calculated a performance measure: For the learning phase, we calculated how much participants learnt about the system's links, for the application phase how close they got to the goal states.

Ecological validity of the task. Using an artificial learning task in a laboratory allowed us greater control of learning, but it is clearly a different task to the complex environment of the classroom. However, our focus was on the process by which motivation and cognition interact, and there is no reason to expect this process to differ between environments, regardless of how complex are the factors affecting motivation and cognition. The critical issue is whether we adequately measured and sampled the range of values for our motivational and cognitive variables. Biology-lab appears to do this, as previous studies have found that participants find it challenging (in this study on a seven-point scale [1=low challenge, 7=high challenge], M=4.85, SD=.91), use a variety of strategies, and find the task difficult (only some reach the goal states). We will return to the issue of generalisability in the discussion.

Method

Participants

Forty-four university psychology students and high school students in Potsdam participated in the study, for which they received DM 25 each.

Procedure

Before explaining the biology-lab task, we told participants that it was very important for us to learn about what they are thinking during the experiment. Therefore, they should talk aloud while working with the system. When doing verbal protocols, Ericsson and Simon (1993, p. 376) recommended a short exercise, which is multiplying 24 times 34 while talking aloud. To practise talking aloud, we had participants do this exercise. Then they read a description of the task.

Vollmeyer et al. (1996) showed that a good strategy for learning about the system was to vary only one input variable at a time, which is our high systematicity category. This strategy was also described in Bandura and Wood (1989), and Putz-Osterloh (1993). We explained this strategy to all participants in order to reduce the variance of their performance. After the instructions, they filled out the QCM (*Q*uestionnaire on *C*urrent *M*otivation, Vollmeyer & Rheinberg, 1998) measuring their initial motivation on the four factors: *mastery confidence*, *incompetence fear*, *interest*, and *challenge*. Then they started manipulating the inputs of the system to try to induce the underlying structure shown in Figure 1. While working with the system they were allowed to take as many notes as they wanted as well as use a calculator.

After each of the three learning rounds participants filled out the structure diagram (see below) and answered the motivational state questionnaire. When the learning phase was finished, participants were asked to reach the goal states which were Thyroxin on 700, Histamine on 900, and Serotonin on 50. The experiment took about two hours.

Verbal protocols

Ericsson and Simon (1993) described how verbal protocols should be used. They concluded that concurrent verbalisations while learning have positive effects on learning because explicitly formulating rules helps knowledge acquisition. However, participants who had to verbalise took more time to finish the task (Deffner, 1984). In addition, when the task is difficult, participants stopped talking (Ericsson & Simon, 1993). Therefore, this method creates a lot of missing data in difficult tasks as participants stop talking aloud. Ericsson and

Simon recommended that as soon as participants become silent, they should be asked to continue talking. However, motivation could be reduced if the experimenter interrupted the learning process too often. Given that we are interested in motivation, we decided not to follow this recommendation completely, but to remind participants only at certain times. Otherwise the experimenter was not in the room.

Measures

Initial motivation. With the QCM, we measured the motivational factors challenge (e.g., "This task is a real challenge for me", "If I can do this task, I will feel proud of myself"), mastery confidence (e.g., "I think everyone could do this task", "I think I am up to the difficulty of the task"), incompetence fear (e.g., "I'm a little bit worried", "I'm afraid I will make a fool out of myself") and interest (e.g., "After having read the instructions, the task seems to be very interesting", "I would work on this task even in my free time") .

Mediating variables. Seven mediating variables were measured in order to investigate the process linking initial motivation to the learning outcomes: (1) strategy systematicity, (2) motivational state, (3) hypothesis testing, (4) analysis of results, (5) strategy for reaching the goal states, (6) metacognition, and (7) emotional reflection. The last five of these variables were coded from the participants' verbal protocols.

Mediator 1: Strategy systematicity. To measure how systematically participants explored the system, we categorised each of the 18 trials into one out of the following three categories.

High systematicity was assigned when one input was varied, and the other two were kept constant. For example, a participant entered 10 for Medicine A, 0 for Medicine B, 0 for Medicine C. This strategy allowed participants to discover the system's structure, as they can observe which outputs a single varied input variable changed in the system. We recommended this strategy to the participants at the beginning of the study.

Medium systematicity was assigned when multiple inputs were varied, but a systematicity could be recognised. For example, a participant entered 100 for Medicine A, 10 for Medicine B, 10 for Medicine C; or, 100 for Medicine A, 100 for Medicine B, -100 for Medicine C.

Low systematicity was assigned when a useful systematicity could not be recognised. For example, a participant varied each input by the same amount (e.g., 10 for Medicine A, 10 for Medicine B, 10 for Medicine C). This is systematic, but futile, because it can not help with learning about the structure.

The categories for strategy systematicity as well as categories for the verbal protocols were coded by multiple raters. To check interrater reliability, 180 trials were coded by two raters and we calculated reliability with Cohen's κ (Cohen, 1960). For all other trials, strategy and protocols were coded by only one rater.

For the strategy systematicity we received a Cohen's κ=.94. To calculate a strategy systematicity score, we ranked a trial's systematicity from one to three, with a value of three indicating a high systematic strategy for a trial, and one a low systematic strategy. Then we averaged the six trials per round to derive a systematicity value for each round.

Mediator 2: Motivational state. At the end of every learning round, participants answered seven questions on a seven-point scale which measured the positive valence and ease of concentration ("The task is fun", "I have no difficulties concentrating on the task", "I think the task needs a lot of effort", "I would love to stop working on the task") and self-efficacy ("I'm sure I will find the correct solution", "It's clear to me how to continue", "I think I won't master the task"). The self-efficacy items were similar to those used in studies by Bandura and Wood (1989), Cervone, Jiwani, and Wood (1991), and Schoppek (1997). These items were averaged as they were homogenous (Round 1, Cronbach's α=.90; Rounds 2 and 3, Cronbach's α=.91). In an earlier study (Vollmeyer, Rollett, & Rheinberg, 1997) we used only three out of the seven items, however, the three and seven items are highly correlated (Round 1, r=.95; Rounds 2 and 3, r=.96).

Mediators 3-7: Verbal protocols. We wanted to investigate how participants are thinking and feeling while exploring the system. To do so, we coded their verbal protocols for *metacognition, emotional reflections*, and the cognitive aspects: *hypothesis testing, analysis of results, strategy for reaching the goal states.*

Hypothesis testing indicated what level of hypotheses a participant formulated before entering numbers for the input variables. The categories were: *no hypothesis testing* (i.e., participants did not say which hypothesis they had), *nonpredictive* (e.g., "Let's see what happens if I change Medicine A."), *testing links* (e.g., "I will try whether Medicine A has an effect on Serotonin."), *testing directions or weights* (e.g., "Perhaps Medicine A affects Serotonin with +2."). Two raters had an agreement of κ=.79. As we assumed that testing directions and weights is the most informative way to test hypotheses in this system whereas having no hypothesis is the least informative, we ranked this variable from one to four. A value of one indicated no hypothesis testing, and a value of four indicated testing of directions and weights. These ranks were averaged over the six trials of each round to yield an hypothesis testing score.

After each input participants analysed the changes in the output variables, which we refer to as *analysis of results*. The categories were: *no analysis* (participants did not say whether or how they analysed the results), *simple analysis* (e.g., "Why did Serotonin change?"), *organised analysis* (e.g., rule induction from relating changes to their effects), *summarising* (e.g., "That's what I know now, I still have to learn..."). For these categories, two raters had an agreement of κ=.77. We also assumed a hierarchy for this variable. The category no analysis was given a rank of one and summarising a rank of four. Again we averaged these ranks across the six trials of each learning round.

The *strategy for reaching the goal states* was coded as: *no strategy* (i.e., participants did not say how they tried to reach the goal states), *trial and error* (e.g., "Let's give in a 10."), *pushing* (e.g., "The difference to the goal state is 20, so let's add something to Medicine A."), *calculating* (e.g., "If the difference to the goal state of Serotonin is 100 then I have to add 50 to Medicine A."). For this variable, two raters had an agreement of κ=.76. As having no strategy should be least effective and calculating the most, we ranked the categories from one (no strategy) to four (calculating) and averaged the ranks across the six trials of each learning round.

For *metacognition* we had two categories: *planning* (e.g., "What do I do next? What is necessary?"), and *self control* (e.g., "I have to concentrate more").

Emotional reflection was recorded with the categories: *failure* (e.g., "... and I thought Serotonin would increase."), *confusion* (e.g., "I don't know what to do next."), and *success* (e.g., "Exactly what I expected.").

Dependent variables. We measured performance for the learning phase (structure score) as well as for the application phase (goal achievement).

(1) *Structure score* (acquired knowledge). After each round of the learning phase, participants had to complete a diagram, similar to the one in Figure 1 but with all links and weights omitted. Using this diagram they had to indicate their knowledge about the system's structure by drawing a link between an input and an output, if they noticed a relationship. Each link could be given a direction (+/-) and a weight, if participants thought they knew how strong the impact was. To indicate that an output had a decay participants could write a weight into the empty circle attached to an output.

The structure score consisted of (1) the number of correct links between the inputs and the outputs, (2) the number of correct directions (+/-), and (3) the number of correct weights. The sums for the correct links and the correct directions were corrected for guessing, in that the number of correct entries (hits) was divided by the maximum number of correct hits (see Woodworth & Schlosberg, 1954, p. 700). This structure score varied between 3.0 (best value) and a theoretical minimum of -1.8. (It was negative if participants incorrectly guessed too much.)

(2) *Goal achievement.* Goal achievement in reaching the goal state during application phase was computed as the sum of the absolute differences between the target and the obtained number for each of the three output variables. As this measure produced a skewed distribution, the variance was corrected by applying a logarithmic transformation (ln). Goal achievement was computed for each of the six trials that comprised each round in the application phase, in order to determine how participants were able to approach the target

goal. As there was no difference in performance between trials, the mean error for the six trials was used. However, this meant that high scores were indicators of poor performance. So that all performance measures would be in the same direction, we subtracted all these scores from an arbitrary constant.

Results

After the first round of the learning phase, five participants said they knew everything about the system and wanted to see the goal states. A further five participants wanted to start the application round after the second round. Thus, we analysed protocols from 44, 39, and 34 participants in Round 1, Round 2, and Round 3, respectively. The application round was completed by all 44 participants.

Verbal protocols

One aim of the study was to investigate whether the thinking aloud method could provide additional information about the effect of motivational factors on learning, especially with regard to cognitive and metacognitive aspects. First, we checked whether participants kept talking aloud throughout the learning rounds. Table 1 shows that the number of classifiable trials declined over the learning rounds. For example, the percentage of trials on which no hypothesis was formulated aloud increased from 22% in Round 1 to 63% in Round 3. Similarly, there was a decline in trials classifiable on analysis of results. This suggests that verbal protocols may not give a full picture of the learning processes. That verbalisations may hinder insight was shown by Schooler, Ohlsson, and Brooks (1993). Dominowski (1998) provides an overview on the pros and cons on verbalisation and problem solving.

Table 1

Verbal protocols: Number of trials classified into each category for each round, together with that number as a percentage of the total number of trials. Total number of trials in a round is the number of participants multiplied by six

Total trials	Round 1 264 (100%)	Round 2 234 (100%)	Round 3 204 (100%)	Round 4 264 (100%)
hypothesis testing:				
- no hypothesis testing	59 (22%)	109 (47%)	129 (63%)	
- nonpredictive	136 (52%)	50 (21%)	26 (13%)	
- links	43 (16%)	36 (15%)	31 (15%)	
- directions, weights	26 (10%)	39 (17%)	18 (9%)	
analysis of results:				
- no analysis	64 (24%)	99 (42%)	120 (59%)	
- simple	14 (6%)	4 (2%)	12 (6%)	
- organised	135 (51%)	89 (38%)	49 (24%)	
- summarising	51 (19%)	42 (18%)	23 (11%)	
strategy for reaching goal:				
- no strategy				84 (32%)
- trial and error				23 (9%)
- pushing				55 (21%)
- calculating				102 (38%)
metacognition:				
- no metacognition	256 (97%)	212 (91%)	197 (97%)	
- planning	8 (3%)	21 (9%)	7 (3%)	
- self-control	0 (0%)	1 (0%)	0 (0%)	
emotional reflection:				
- no emotional reflections	247 (94%)	200 (85%)	184 (90%)	187 (71%)
- failure	6 (2%)	11 (5%)	10 (5%)	52 (20%)
- surprise, confusion	7 (3%)	19 (8%)	4 (2%)	11 (4%)
- success	4 (1%)	4 (2%)	6 (3%)	14 (5%)

Another problem we noticed was that participants verbalised few emotional reflections or metacognition (see Table 1). In the learning phase, most of the trials could be categorised as non-emotional. However, in the application phase there was a greater number of trials for which expressions of failure were coded (20%). Therefore, we could successfully classify participants as expressing failure, at a time they were likely to be confronted with it (i.e., when they must reach a difficult goal state). Metacognition was also difficult to analyse because there were few instances. During learning very few participants stated their plans or said how they controlled their learning. For these two metacognitive variables there were too few instances to analyse them with regard to initial motivation or performance. In the application phase, participants talked aloud more. Only in 32% of the trials did participants not say which strategy they used for trying to reach the goal states.

In summary, we had three protocol variables with enough instances to enable us to study their relationship to motivation and performance. All of these were measures of cognitive aspects: hypothesis testing, analysis of results, strategy for reaching goal.

Influence of initial motivation (QCM) on hypothesis testing and analysis of results

For this analysis the data is missing for one participant who did not fill out the QCM. The hypothesis was that participants who have high scores on interest, perceive high challenge, high mastery competence, or low incompetence fear should have been more effective at hypothesis testing and at analysis of results. This was because we expected them to think deeply about the system. Therefore, we correlated the initial motivational factors with the two analysable variables which were extracted from the verbal protocols in the learning rounds. Effective hypothesis testing could not be predicted by either challenge (for Rounds 1 to 3, p's>.60), or mastery competence (for Rounds 1 to 3, p's>.20). A pattern in the right direction, but not significant, could be found in that more interested participants had more effective hypothesis testing and participants with less incompetence fear had more detailed hypotheses. The effects of initial motivation were also small for analysis of results: For none of the three rounds we did find effects of challenge (p's>.20), mastery competence (p's>.40), or interest (p's>.20). Only incompetence fear showed the expected, but not significant pattern, in that participants with high fear were worse at analysing the results.

Influence of hypothesis testing and analysis of results on the learning process

In the learning phase, we measured the two mediating variables, strategy systematicity and the motivational state, as well as the performance (structure score). As hypothesis testing and analysis of results are new variables in our model we report their correlations with the above stated variables (see Table 2). Participants with more systematic strategies tested hypotheses more effectively and analysed the results more carefully over all three rounds. When participants were testing hypotheses more effectively, they had more fun and were more sure that they would learn the system (i.e., had more positive motivational state) than with less effective hypothesis testing. This effect was not true for analysis of results for which all correlations turned out to be not significant (p's>.12). A higher structure score was obtained when hypothesis testing and analysis of results were more sophisticated.

In sum, two cognitive variables from the verbal protocols correlated with the learning process in that hypothesis testing was associated with motivational (motivational state) and cognitive variables (strategy systematicity, structure score) but analysis of results was associated only with the cognitive ones.

Table 2

Correlations between hypothesis testing, analysis of results and strategy systematicity, motivational state, structure score

	Round 1 N=44		Round 2 N=39		Round 3 N=34	
correlation between:	r	p	r	p	r	p
hypothesis testing and strategy systematicity	.43	.003	.31	.061	.30	.100
hypothesis testing and motivational state	.41	.005	.29	.075	.26	.150
hypothesis testing and structure score	.33	.029	.45	.004	.39	.023
analysis of results and strategy systematicity	.37	.013	.26	.110	.25	.170
analysis of results and motivational state	.24	.120	.18	.290	.06	.720
analysis of results and structure score	.41	.006	.43	.007	.04	.840

Influence of application round strategy

Those participants who chose a better strategy in the application round, which was one of the three cognitive aspects, had more fun and were more sure about learning the system (i.e., motivational state), $r(44)=.31$, $p=.045$, and had more knowledge about the system, $r(44)=.49$, $p=.001$, at the end of their last learning round. Choosing a better strategy helped participants come closer to the goal state, $r(44)=.32$, $p=.032$.

The cognitive-motivational process model

Consistent with our cognitive-motivational model, we tested the predictions that initial motivation (mastery competence, incompetence fear) would influence performance via the mediating variables of strategy systematicity and motivational state. To analyse this process, the appropriate statistical analysis is a path analysis. Ideally, the new mediators measured from the verbal protocols should be added into the model. Unlike our previous study (Vollmeyer et al., 1997), ten participants finished before the third round. Therefore, we analysed the individual last round that each participant completed (i.e., for those who finished in the first round we analysed Round 1, for those who finished in the second round Round 2, etc.). Thus in the present study we lost the information showing how variables develop and interact over the learning rounds. To our previous model, we added the cognitive aspects (hypothesis testing, analysis of results, and strategy for reaching the goal) and calculated a structural equation model using Bentler's (1992) program. The result can be seen in Figure 2. Fitting the theoretically derived model to the data gave a high model fit, $CFI=0.98$, $X^2(19)=21.50$, $p>.31$.

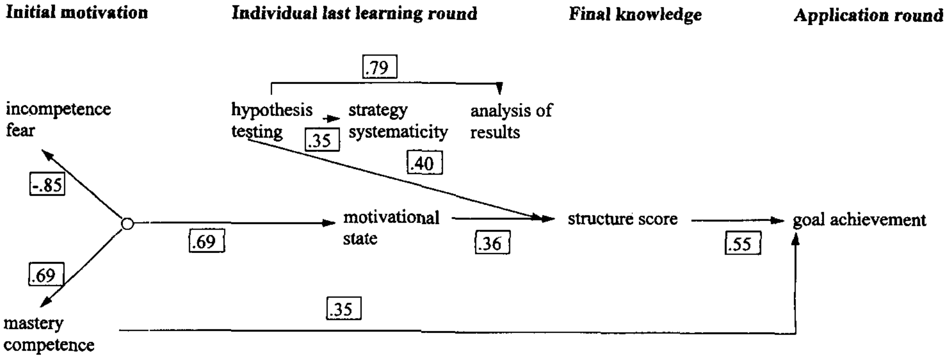

Figure 2. Path analysis for the cognitive-motivational process model

As incompetence fear and mastery competence are highly correlated, $r(44)=-.59$, $p=.001$, we combined them into a latent variable as we did previously (Vollmeyer et al., 1997). This initial motivation affected motivation during learning. As a good strategy was explained before working with the task, almost all participants followed our instruction on the first three trials of Round 1 (trial 1: 96%, trial 2: 96%, trial 3: 98%). As there is only a small variance we did not expect strategy to be affected by initial motivation. However, having a detailed hypothesis should increase persistence with a more systematic strategy, and assist with analysing the results more carefully. The model in Figure 2 shows, that these assumptions were confirmed. Having a more detailed hypothesis and a more positive motivational state (i.e., more fun, and a higher expectation of learning the system) led to more knowledge about the system's structure (structure score). This knowledge was helpful for reaching the goal state. Unlike in our previous study (Vollmeyer et al., 1997), it was not the motivational state during learning which was associated with goal achievement. In the present study, initial mastery competence directly affected how well the goal states were reached. Beside these differences across studies, there are also differences between what is shown by the individual correlations and by the path analysis. First, although the strategy for reaching the goal states was correlated with the mediating and performance variables, the variance in the model was better explained with other variables. Second, the same was true for interest. Interest correlated with mediating and performance variables, however, the latent variable explained more variance in the model.

Discussion

The aim of this study was to integrate variables for the qualitative cognitive and metacognitive aspects of learning into our cognitive-motivational model. To do so, we first had to test whether we could replicate our empirical model. The replication was partially successful. In addition, we could integrate the new cognitive aspects, but not the metacognitive ones. As in our previous studies (Vollmeyer et al., 1997, 1998), the path-analysis showed that initial motivation (incompetence fear and mastery competence) affected knowledge acquisition through motivational state. However, there were also differences: (1) Strategy systematicity did not affect knowledge acquisition (but hypothesis testing did). (2) Motivational state during learning did not affect strategy systematicity. (3) Motivational state had no effect on the performance in the application round (but initial motivation did).

Verbal protocols

Deviations from our previous model may be partially due to the fact that different learners completed different number of rounds. Therefore, we restricted our analysis to the individual last learning round which may have led to a loss of relevant process characteristics that we found in our previous path-analyses.

The deviations could also be explained as due to the use of the thinking-aloud technique, which we added in order to measure cognitive and metacognitive aspects. It is possible that this technique created an environment in which participants thought more deeply, as they were forced to verbalise their thoughts, which in turn would emphasise the cognitive aspects of the task. This could be the reason why hypothesis testing had such a central position (it was linked to systematicity, analysis of results, knowledge acquisition) in the learning process. The emphasis on cognitive aspects may also be responsible for the finding that the motivational state affected knowledge acquisition, but not its application (for which mastery confidence was a better predictor).

Apart from the possibility that the thinking-aloud technique may have emphasised the cognitive aspects of the task, there was a more serious problem with applying this technique to this task: We lost a lot of data because participants stopped talking aloud. Participants also complained that verbalising their thoughts was strange for them. Therefore, data on verbal protocols had a selective bias in this experiment, that only those who were verbalising, revealed the true values of the variables we used to measure the learning process. The fact that participants did not like thinking aloud may have hindered them from expressing their emotions or describing how they controlled their learning.

Metacognition – Metacognitive experience

What does our study say about metacognition or metacognitive experience? Unfortunately, the verbal protocols did not reveal how participants planned and controlled their learning. Using verbal protocols for studying the effects of metacognition on learning, may require continually reminding participants to talk aloud. However, this intervention could be detrimental to motivation. Whether this means that this is a fundamental limitation to studying motivation and metacognitive processes, is a question for further studies.

Our modelling showed the importance of process variables recorded during learning. Given that metacognitive experience overlaps with motivational state (e.g., both measure expectancy of learning the system among other measures), this suggests that in order to understand the relationship of metacognitive experience to learning, an emphasis should be put on measures during learning.

Future research

Up to now our results have been validated for only a single laboratory task. This limits our conclusions to situations in which people have to induce rules from observations presented on a computer. However, as multimedia learning gains importance, a next step will be to transfer.

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Notre modèle de processus cognitivo-motivationnel (Vollmeyer & Rheinberg, 1998), suppose que les facteurs motivationnels (i.e., confiance dans sa maîtrise, crainte de l'incompétence, intérêt, et défi) affectent la performance par l'intermédiaire de médiateurs. Des études antérieurs (Vollmeyer, Rollett, & Rheinberg, 1997) ont montré que la systématicité de la stratégie et l'état motivationnel pendant l'apprentissage d'un système complexe. Les médiateurs pontentiels peuvent concerner d'autres aspects cognitifs et métacognitifs, étant donné que les apprenants les plus motivés (niveau élevé de confiance dans sa maîtrise, faible crainte de son incompétence, niveau élevé d'intérêt) analysent plus profondément. On a recueilli les protocoles verbaux de 44 étudiants qui apprenaient à contrôler un système *dynamique complexe. On a mesuré leur motivation initiale (sur les quatre facteurs spécifiés) puis, durant l'apprentissage, on a évalué leur systématicité stratégique et leur état motivationnel. En plus, on a analysé les protocoles verbaux afin d'obtenir des indicateurs de processus cognitifs et métacognitifs d'apprentissage. Les mesures de performance utilisées ont été des niveaux d'acquisition et d'application de connaissances. On a alors répliqué le modèle de processus cognitivo-motivationnel à ces données. Les aspects cognitifs qualitatifs ont été introduits, en plus, comme médiateurs, mais les résultats relatifs à la métacognition ont été problématiques du fait, en partie, que les participants ont fourni relativement peu d'énoncés méta-cognitifs exprimés clairement.*

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Current theme of research:

Motivation and learning, problem solving.

Most relevant publications in the field of Psychology of Education:

Vollmeyer, R., Burns, B.D., & Holyoak, K.J. (1996). The impact of goal on strategy use and the acquisition of problem structure. *Cognitive Science, 20,* 75-100.

Vollmeyer, R., Rollett, W., & Rheinberg, F. (1997). How motivation affects learning. In M.G. Shaffo & P. Langley (Eds.), *Proceedings of the Nineteenth Annual Conference of the Cognitive Science Society* (pp. 796-801). Hillsdale, NJ: Erlbaum.

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Current theme of research:

Incentives of learning activities, motive modification training, motivation and learning.

Most relevant publications in the field of Psychology of Education:

Rheinberg, F. (1996). Von der Lernmotivation zur Lernleistung. Was liegt dazwischen? [From motivation to learn to learning outcome. What's between?]. In J. Möller & O. Köller (Eds.), *Emotion, Kognition und Schulleistung [Emotion, cognition, and academic achievement]* (pp. 23-51). Weinheim: PVU.

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