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Regulative processes in individual, 3D and computer supported cooperative learning contexts

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Abstract

Three studies of student regulation of learning were undertaken. In the first study, the temporal organization of the self-regulation process was examined within an individual learning context. Multilevel analysis showed linear and quadratic relations between self-regulation process and the phase of learning. An unexpected negative direct relation between self-regulation and test performance was only found for the process of "directing". In the two other studies, collaborative computer learning within a 3D environment, on the one hand, and within the context of literacy practices, on the other hand, was examined. Self-regulative processes as "monitoring," "directing," and "testing" occurred less frequently than "grounding" and "common agreement" activities. In all three studies, the students rarely "orient" themselves towards the learning task. It is concluded that the adequacy of regulation and not the frequency is important for student learning.

Keywords: Self-regulation; Group regulation; CSCL; 3D-environment; Metacognition; Primary and secondary education

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1. Introduction

A quick look over the shoulders of kids who are interacting with each other and surfing the Internet is like looking at the future of learning. The kids consult with peers, friends, and experts; they Google® (i.e., search) and select information; they seek explanations; they spontaneously help others when working on assignments; and they even create their own virtual worlds when interacting in 3D environments unimpeded by the boundaries of classrooms or countries. Students often attain knowledge and gain a deeper understanding of a topic with little or no teacher involvement. Knowledge is no longer transferred by teachers; teachers do not have a monopoly on student learning; and teachers are in more of a position to scaffold student learning than transfer information directly.

Internet interaction is in keeping with many other innovations occurring in both schools and workplaces. Learners are more responsible than ever for their own learning. And understanding why learners and particularly students differ so greatly in their ability to learn is even more complex with the observed shift in the locus of responsibility for learning.

Differences in learning performance are often attributed to variations in ability, intelligence, socio-economic background, teacher characteristics, prior knowledge, and so forth. More recently, the contributions of various metacognitive processes have also been recognized. Metacognition is typically defined as knowledge of one's information processing activities, one's use of problem-solving strategies, one's learning-related knowledge, one's motivation, and one's concentration. And in addition to knowledge of the learning process itself, *regulation* constitutes an important component of metacognition (Brown & Delaoche, 1978). Regulation typically refers to the ability of the individual or group to select and direct (i.e., manage) actions according to plans, goals, and standards. Boekaerts and Simons (1993) further distinguish three aspects of metacognition, namely metacognitive beliefs, metacognitive knowledge, and metacognitive skills. Metacognitive beliefs are the "(...) relatively general, broad ideas of people about cognitions and learning(...)" (p. 266). Metacognitive knowledge is knowledge of the cognitive functioning of the individual and others: not only one's own thinking, memorization, imagination, and reasoning but also that of others. Metacognitive skills concern the "(...) active guidance of one's own cognitive processes(...)" (p. 266) and may also be referred to as self-regulative skills at times.

Some examples of self-regulative skills are as follows (Boekaerts & Simons, 1993; De Jong, 1992; Vermunt, 1992).

- *Orienting*. Thinking about desired learning goals and retrieving knowledge from memory with regard to personal learning skills, testing, time available, similar tasks, etc. The learner mobilizes such information as it is expected to be necessary to complete the task at hand.
- *Planning*. Determination of learning goals, planning of learning activities and their sequence, temporal planning, and prediction of the course of the learning process.

- *Monitoring*. Active observation of learning activities, recording of learning progress, recording of comprehension, noting of task features, etc.
- *Testing*. Checking of emerging comprehension via translation into own words, posing of questions, thinking of problems, drawing of conclusions, and comparison.
- *Restoring/directing*. Deciding to change the planning, devotion of extra attention to more difficult components, requests for help, and experimentation with new learning activities.
- *Evaluating*. Answering test questions, rehearsing read information by heart, contemplation of the progress of the reaching the learning goal.
- *Reflecting*. Thinking about the course of learning and information processing with future processes in mind.

The aforementioned self-regulative skills are made easy to observe within the context of learning by having students think aloud. And for this purpose, De Jong (1992, p. 14) has operationalized metacognition as: "(...) the concrete, perceptible cognitive activities that people use to orient themselves towards a learning task; monitor the learning process and progress; and further test, diagnose, and direct the performance of a learning task".

When novices and experts have been compared with regard to metacognitive skills (i.e., self-regulative skills), the following differences have been found. Experts are (a) better than novices at monitoring their problem solving; (b) better at judging the difficulty of problems; (c) more aware of the errors that they make; and (d) more skilled at the allocation of their time (Glaser & Chi, 1988; Matlin, 1994). Analysis of several hundred think-aloud protocols for learning from texts showed successful students to use more regulative activities than unsuccessful students and this difference to explain anywhere from 19% to 60% of the variance in learning results depending on the type of learning task involved (De Jong, 1992). In other words, and in line with Resnick's thesis (1989), learning is not a matter of simply recording information but of interpreting information and the learner thus playing an *active* role. The learner must contemplate, perform, and regulate certain learning activities. And according to several authors, the integration of knowledge and adequate management of various learning strategies clearly facilitate learning (Brown, 1979; Brown & Delaoche, 1978; Corno & Randi, 1999; Flavell, 1976; Zimmerman & Schunk, 1989).

The ability to regulate one's own learning thus constitutes a key element of student performance, but we have very little insight into just how the relevant regulative processes actually occur. The studies presented here seek a basis how to link the use of particular regulation strategies to successful task performance. In the end, it may be possible to determine which regulation strategies are actually required to perform well within individual and CSCL environments.

In the research presented here, the temporal organization of self-regulative skills in the learning process within both individual learning and cooperative learning contexts will be examined. In the first study, the way that various self-regulative processes unfold within an individual learning context is examined. The second and third studies examine two computer supported learning environments requiring students to collaborate to achieve a common goal and how the students regulate their learning under such circumstances will be examined.

2. Study 1: regulation within an individual learning context

In general, the problem-solving or learning process can be distinguished in: (1) an orientation or analysis phase, (2) a planning phase, (3) an execution phase, and (4) an evaluation phase (De Jong, 1986; Mettes & Pilot, 1980; Van der Sanden, Schouten, Deijkers, & Van Oirschot, 1986; Vanderlocht & Van Damme, 1989). According to Veenman (1993, 1997), learners then use a particular *working method* to proceed through the various phases of the learning process, and the particular working method used by a learner can thus be regarded as an operationalization of his or her metacognitive skills. An *effective* working method involves a well-organized set of self-regulative activities that enables one to pass through the various phases of the learning process in an orderly and systematic way (e.g., a deep orientation, systematicity, accuracy, evaluation, elaboration). That is, one's learning activities must show some coherence and internal logic with regard to both past and future activities: orienting activities should occur primarily during the orientation or analysis phase of the learning process; evaluation activities should occur primarily during the evaluation phase of the learning process, and so forth.

On the basis of think-aloud protocols, De Jong (1992) distinguished four regulative processes: orienting, monitoring, directing, and testing. Each of these regulative processes can be further operationalized in terms of several self-regulative activities.

- *Orienting* can be operationalized as: looking at an index, browsing through a text, referring to prior knowledge, noting or expressing gaps in prior knowledge, noting own positive or negative learner characteristics ("I'm not very good at learning vocabulary"), and mention of a possible learning strategy prior to learning.
- *Monitoring* can be operationalized as: recording positive or negative progress, recording comprehended or noncomprehended elements, checking study time, and knowing which learning activities to employ. Given that the regulative activities associated with monitoring have both action and evaluative aspects, it can be assumed that the relevant activities will be primarily observed during the execution and evaluation phases at the end of the learning process.
- *Directing* can be operationalized as: the selection and assignment of certain learning activities, identification of a problem, subdivision of problems into subproblems, and attempts to solve a problem by the posing of questions. Given that the regulative activities associated with directing involve planning, action, and evaluative elements it can be assumed that the relevant activities will be mostly observed during the planning, execution, and evaluation phases of the learning process.

- *Testing* can be operationalized as: checking whether sufficient information has been extracted, whether something has been understood, and whether learning goals have been achieved. The regulative activities associated with testing are expected to occur primarily during the final evaluation phase of the learning process.

Two other nonregulative activities have been found to characterize the think-aloud data analyzed by De Jong (1992) namely learner transformation activities and external interventions to stimulate thinking aloud.

- *Transformation activities* are all mediating learning activities that effect the internalization of information. Examples of transformation activities are: reading, rehearsing, copying, calculating, and adding information or experiences. Transformation activities are clearly executive in nature and can therefore be assumed to occur primarily during the execution phase of the learning process.
- *Interventions* are remarks not directly related to the learning process. An example of an intervention is the experimenter reminding the student to keep thinking aloud after a relatively long pause or nonverbal communication suggesting that the learning process has been interrupted. Clear assumptions regarding possible associations between external interventions and the different phases of the learning process were not apparent. Interventions were, however, kept in the analyses as they have proved very informative for understanding the learning process.

On the basis of what we know about learner's self-regulation and the different phases of learning distinguished above we hypothesized that (1) the occurrence of the different types of self-regulative activities can be predicted by the phase of the learning process, and (2) the probability of certain self-regulative activities during a particular phase of the learning process will differ for more versus less successful students. In order to illustrate our expectations with regard to (1), a graph of the expected probability of orienting and evaluative self-regulative activities during a fictitious learning process is presented in Fig. 1.

2.1. Method

2.1.1. Participants

The participants were 36 Dutch pre-university students in their first year of high school in the Netherlands, selected on the basis of their national achievement scores (i.e., CITO performance). High performing boys ($N = 10$) and high performing girls ($N = 10$) (i.e., CITO scores in the range of 548–550) were asked to participate. Low performing boys ($N = 11$) and low performing girls ($N = 5$) (i.e., CITO scores in the range of 537–540) were also asked to participate. The average age for both groups was 12 years, and participation was voluntary and during school time.

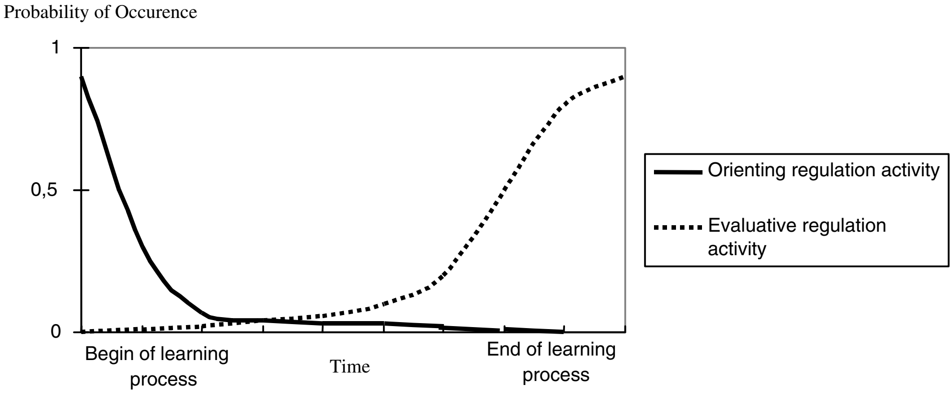

Fig. 1. Probability of occurrence of regulative activities during a fictitious learning process.

2.1.2. Learning and test materials

The learning materials consisted of texts on probability calculus and the solution of probability problems. The learning task mainly called upon reading-comprehension and problem-solving skills and in a very low extent on math skills. The test materials consisted of nine probability calculation problems and one knowledge question.

2.1.3. Design and procedure

Particularly high or low national achievement test scores did not necessarily mean high test scores in the present study. For this reason, the test scores of the participants on the materials used in the present study and not their national achievement scores were used to divide the participants into different groups for comparison purposes. During the first week of the study, two preparatory sessions, a half hour each, were undertaken with the students to familiarize them with the think-aloud procedure. The experimental session was conducted the next week near the schools in small mobile learning units. Prior to the start of the learning task, the students were told that they would later be asked to take a test. They were given an indication of the type of questions included in the test, reminded that they should "learn aloud" (i.e., think aloud), and told that their learning aloud would be audiotaped. The experimenter provided no feedback with regard to the content of the learning task or participant's learning progress. Each session was limited to 30 min. The students completed the test immediately after the experimental session. Two weeks later, they completed the same test but with the questions presented in a different order.

2.1.4. Empirical data

The data consisted of the transcribed think-aloud protocols. Although there may be doubts about whether what students say is the same as what they think, research in the 1980s showed think-aloud verbalizations to be directly related to cognitive activities (Carpenter & Just, 1986; Deffner & Rhenius, 1985; Ericsson & Simon, 1980, 1984; Muth, Britton, Glynn, & Graves, 1988).

Differences in the interpretation of the protocols and specific verbalizations may also exist across coders. Each of the 531 protocols was therefore divided into "units of regulation" or so-called meaningful units (Wouters & De Jong, 1982). A regulation unit is that part of a think-aloud protocol showing a regulative activity to have taken place. The coders followed a coding scheme and distinguished the four regulative processes of orienting, process monitoring, directing, and testing and the two categories of transforming and intervention. The interrater reliability for the four raters across four different learning tasks and calculated for 48 protocols all proved significant (df = 52; $p = 0.001$) with an average of *.98* (SD = 0.11).

2.1.5. Data analysis

The coded regulation units were sorted by student and learning task but kept in chronological order (i.e., numbered according to their position in the sequence of units). Clock time or other information on the duration of the units was not available, but time was preserved as a variable by keeping the units in chronological order and thereby making information regarding their sequential relations to the beginning and end of the learning process available and information with regard to their relations to the other intra-individual units available. The first unit was numbered 1, the second unit numbered 2, etc. The maximum number of units found per student was 252. Given that the number of units could differ from student to student and from learning task to learning task, the numbers need to be synchronized to enable comparison across participants. For this purpose, the sequential numbers assigned to the individual units in the protocols were transformed by assigning a value of 1 to the starting point (i.e., the first unit) and a value of 252 to the end point (i.e., the final unit representing the maximum number of activities observed during the learning sequence). The numbers of the units between the first and final units were then rescaled by multiplying the initial unit value by the ratio of 252 to the total number of units coded for the individual student. Consider a student with a total of 141 regulative activities (i.e., 141 initial units). Each initial number is transformed by multiplying it by 252/141 (or 1.787). The initial number 1 thus becomes $1 * (252/141) = 1.787$; the initial number 2 thus becomes $2 * (252/141) = 3.574$; the initial number 3 thus becomes $3 * (252/141) = 5.361$ and so forth with the last activity becoming $141 * (252/141) = 252$.

Given that the analysis model works with time and powers of time as explanatory variables, a new problem arose. If the rescaled sequential values and particularly the higher values are raised to the second, third, or higher powers, very large values will be obtained for the explanatory variables and extremely low regression weights were obtained as a result. Serious problems were also expected due to arithmetic imprecision (Van den Bergh & Rijlaarsdam, 1996) The rescaled sequential values were therefore standardized by subtracting the sample mean and dividing this by the standard deviation.

The dependent variable in the present study was the probability of the occurrence of a particular regulative activity as a function of time. In most cases, the frequencies of the specific regulative activities were too small to be analyzed; grouping the frequencies of the regulative activities according to the more general regulative process, however, yielded sufficient frequencies. For each of the regulative processes of orienting, monitoring, directing, and testing, the relevant regulation units were scanned and transformed into dummy variables. That is, every regulation unit belonging to a particular regulative process was assigned a 1; every unit belonging to another regulative process was assigned a 0. This procedure was repeated across the four regulative processes. While building and fitting the analytic models, the final test scores for the individual students were added to the models in order to check for whether this information also contributed to the prediction of the dependent variable. Before being added to the model, however, the test scores were centered around the grand mean.

Given our interest in the probability of the occurrence of a specific regulative process over time, growth curves were calculated. Growth curves are described by higher order polynomial functions. And the data were thus analyzed using a two-level model. Level 1 consisted of the observations (i); level 2 consisted of the individual students (j) with level 1 observations nested within. A logit function is applied as link function in order to link the predicted values for the dependent variable to the observed values. The corresponding error function is a binomial distribution. The use of a logit regression model for probability p allows the use of a linear regression model for the logits of the probabilities (cf. Hox, 1995). The observation for student j on occasion i is defined by y_{ij} and the estimate (probability) of y_{ij} is denoted by $\boldsymbol{\pi}_{ij}$. Time, powers of time, and test scores are added to the model as long as they contribute significantly to the estimation of y_{ij}. The full model is written as:

$$y_{ij} = \boldsymbol{\pi}_{ij} + e_{ij} z_{ij},$$

$$\begin{aligned} \log\text{it}(\boldsymbol{\pi}_{ij}) = {} & \beta_{0ij} t^0 + \beta_{1j} t_{ij} + \beta_{2j} t_{ij}^2 + \beta_{3j} t_{ij}^3 + \beta_{4j} t_{ij}^4 + \beta_{5j} t_{ij}^5 + \beta_{6j}\ \text{Score}_{ij} \\ & + [u_{0j} t_0 + u_{1j} t_{ij} + u_{2j} t_{ij}^2 + u_{3j} t_{ij}^3 + u_{4j} t_{ij}^4 + u_{5j} t_{ij}^5 + u_{6j}\ \text{Score}] \\ & \times y_{ij} \sim \text{Bin}(\boldsymbol{\pi}_{ij} n_{ij}), \end{aligned}$$

where z_{ij} has a constant value of 1, which is also true for t^0, which is attached to the intercept, β_{0ij}. The mean of e_{ij} is assumed to be 0 and level 1 variance is constrained to be 1. Other residuals are assumed to have a mean of 0 and a variance that is distributed normally.

In order to estimate the parameters, second-order Taylor expansions and predictive quasi-likelihood (PQL) approximations were applied in combination with residual (or restricted) iterative generalized least squares (RIGLS) residual (or restricted) maximum likelihood (REML) procedures. This guarantees the most unbiased estimates and best approximations of the real values. In cases of nonconvergence, first-order marginal quasi likelihood (MQL) approximations were adopted as a last resort but always with RIGLS/REML.

In the analysis time and test scores (i.e., performance) were used as the independent variables in the regression analyses and thus to predict the probability of a specific regulative process occurring at a particular point in time (t). The dependent variable is modeled as a polynomial function of t. The fixed parameters can be compared with regression weights in classical regression analyses. β_0 represents the weight of the intercept, β_1,β_2, and β_3 represent the weights of time and powers of time. From these weights, β_1, the regression weight for t^1 denotes the linear change in occurrence with t. Regression weight for $t^2\beta_2$ symbolizes the quadratic change, and β_3 denotes the cubic change. Of these regression weights, β_1 was added to the model first. After testing the significance of its contribution to the model, the next weight, β_2, was added. When both weights contributed significantly to the regression equation, they were maintained in the model. If not, β_2 was removed from the model and the contribution of β_3 tested. When adding and testing these weights, two rules of thumb as provided by Van den Bergh and Rijlaarsdam (1996) were followed. The first is that the last regression weight must still contribute significantly to the model. The second is that higher order terms may not be included in the model when lower order terms are not significant. Both rules are aimed at keeping the model as parsimonious (i.e., simple) as possible. β_5 is the weight of the test score of student j. The random parameters define the differences between students.

2.2. Results

In Table 1, the parameter estimates and their significance for each of the regulative processes and other categories of activity are presented.

The mean change in the probability of observing a specific regulative process as a function of time was calculated from the fixed parameter estimates. The calculated values underwent an inverse logit transformation in order to re-transform them back to their original scale. The results are depicted in Fig. 2.

As can be seen, no parameter estimates were observed for the regulative process of *Orienting*. The frequency of self-regulative activities with an orienting nature was probably too small for analysis.

With regard to *monitoring*, significant changes over time could be established (see Table 1 as well). At the very beginning of the learning process, the probability of observing monitoring activities was relatively limited. During the first half of the learning process, the probability of observing monitoring activities increased to approximately twice the initial value. During the second half of the learning process, the probability of observing monitoring activities decreased slightly but then increased. At the end of the learning process, the probability of observing monitoring activities reached its peak (see Fig. 2). In addition, students with relatively high initial values showed higher values across the entire learning process when compared to students with lower initial values. However, a significant effect of test score could not be established.

Directing was the only regulative process in which test scores were found to play a highly significant role (see Table 1, where β_5 is significant). During the learning of students with higher test scores (i.e., the *better* performing students), the probability of directing activities was structurally smaller. Time played a significant role in this prediction as well (see Table 1). Overall, the probability of directing activities was quite stable over time (see Fig. 2). Only slight fluctuations over time were detected. The values at the very beginning of the learning process were relatively high (i.e., between 0.20 and 0.30) with a slight decrease thereafter. During the second half of the

Table 1
Parameter estimates for learning task probability calculus

Regulative process	Effects	Parameter	Estim. (SE)
Orienting	Fixed	β_0 (Interc.)	
		β_1 (t)	
		β_2 (t^2)	
		β_3 (t^3)	
		β_5 (Score)	
	Random	var(U_{0j})	
Process monitoring	Fixed	β_0 (Interc.)	−1.366 (0.12)[b]
		β_1 (t)	−0.350 (0.15)[b]
		β_2 (t^2)	0.471 (0.11)[a]
		β_3 (t^3)	
		β_5 (Score)	
	Random	var(U_{0j})	0.457
Directing	Fixed	β_0 (Interc.)	−1.218 (0.06)[b]
		β_1 (t)	0.294 (0.15)[a]
		β_2 (t^2)	−0.218 (0.11)[a]
		β_3 (t^3)	
		β_5 (Score)	−0.056 (0.02)[b]
	Random	var(U_{0j})	0.050
		var(U_{5j})	0.010
		cov(U_{0j}, U_{5j})	0.026
Testing	Fixed	β_0 (Interc.)	−1.835 (0.10)[b]
		β_1 (t)	0.273 (0.04)[a]
		β_2 (t^2)	
		β_3 (t^3)	
		β_5 (Score)	
	Random	var(U_{0j})	0.287
Other categories			
Transforming	Fixed	β_0 (Interc.)	−1.254 (0.10)[b]
		β_1 (t)	−0.362 (0.04)[b]
		β_2 (t^2)	
		β_3 (t^3)	
		β_5 (Score)	−0.101 (0.04)[b]
	Random	var(U_{0j})	0.270
Interventions	Fixed	β_0 (Interc.)	−2.807 (0.16)[b]
		β_1 (t)	−0.296 (0.06)[a]
		β_2 (t^2)	
		β_3 (t^3)	
		β_5 (Score)	−0.241 (0.08)[b]

Table 1 (*continued*)

Regulative process	Effects	Parameter	Estim. (SE)
Random	var(U_{0j})	0.344	
	var(U_{5j})	0.088	
		cov(U_{0j}, U_{5j})	0.101

[a] $p < 0.05$.
[b] $p < 0.001$.

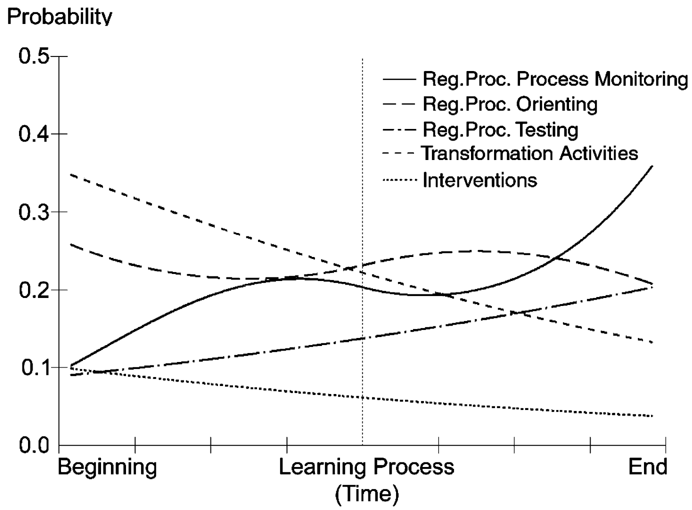

Fig. 2. Probability curves for different regulative processes, transformation activities, and external interventions.

learning process, however, the values increased again to almost the initial levels. As the learning process reached the final phase, the values again decreased slightly.

Although test scores did not contribute to the prediction of *testing*, a significant role of time could be established (see Table 1). The initial values for the probability of observing testing activities were modest at the start of the learning process (i.e., less than 0.10) but showed a steady linear increase during the learning process to final values that were approximately 2.5 times greater than the initial values (see Fig. 2).

Test scores related highly significantly to Transformation activities and Interventions (see Table 1). The initial values for the probability of observing *Transformation activities* were relatively high at the start of the learning process and showed a steady linear decrease during the learning process to final values that were approximately half the initial values (see Fig. 2). The values observed for students with higher test scores were also lower throughout the course of the learning process.

The probability of *Interventions* showed a steady linear decrease during the learning process to final values that were approximately half the initial values. The observed values for students with higher test scores were generally lower throughout the course of the learning process.

For all of the categories of self-regulative activities, it can be said that those students with initially high values generally show higher values through the entire learning process when compared to students with initially lower values. The slopes of the lines differ slightly with some small differences in the final values as a result.

2.3. Discussion

With regard to the process of orienting, there is an absence of significant estimates. We can therefore conclude that students undertake very few task orienting activities. They appear, instead, to take the information they are given for granted and to simply undertake the task in question.

Time plays an important role with regard to the process of monitoring. We can therefore conclude that monitoring is quadratically related to the different phases of the learning process.

Time also played a significant role in the process of Directing and was quadratically related to the different phases of the learning process. Further with regard to the process of Directing, it is noteworthy that only directing activities related to learning performance (i.e., the test results) and that this relation proved negative. Better final test performance was related to the less frequent occurrence of directing activities during the learning process. In combination with the finding that low performers show more transformation activities in relation to their learning results, it seems reasonable to assume that low performers "switch" more from one to another activity in order to find adequate transformation activities. These switches, however, appear to be more a matter of unregulated directing (i.e., trial and error) than effective and efficient directing that takes place on basis of what one knows meta-cognitively about their learning.

With regard to the process of testing, the factor time was again found to have a significant impact. Different from the processes of monitoring and directing, however, testing showed a linear relation to the different phases of the learning process: there was a low occurrence at the beginning of the learning process and an increased occurrence at the end of the learning process.

With regard to the occurrence of transformation activities, there was also a linear relation to the different phases of the learning process. A high occurrence was found at the beginning of the learning process followed by a decrease.

Whether the learning results (i.e., test results) are loosely related to the dynamics of the regulative process or more tightly related to the regulative process has yet to be seen. It is reasonable to assume that the learning results depend on the specific combination of regulative activities undertaken by the learner. However, different combinations of activities are better examined in such microlevel analyses as a concordance analysis (see De Jong, 1992) than in a more general multilevel analysis. In any case, the present analyses showed the learning process to start – as expected – with a high level of transformation processing activities as reading, calculating, writing, copying, and drilling. These activities are gradually replaced by activities of a testing character: summarizing, hypothesizing, and checking. And up until about half way through the learning process, there is a high incidence of monitoring activities, which decrease and then increase towards the end of the learning process. The occurrence of monitoring activities appears to complement the occurrence of directing activities, which show the reverse of the monitoring pattern. The learning process appears to start not with orienting but with directing activities and the occurrence of numerous transformation activities which affect comprehension and reaching the learning goals. Learners appear to search for adequate information-processing activities at the beginning of the learning process and thus monitor the effects of these activities. Halfway through the learning process, such monitoring leads to a continuation of the ongoing information processing activity or a regulative directing activity in order to activate other learning activities. or strategies. It is likely that the increased occurrence of directing activities during the course of the learning process is related to a switch from transformation activities to testing activities and that the results of this switch are also carefully monitored. That is, information transformation activities and testing activities appear to be complementary in the knowledge construction process and coordinated by the regulative processes of monitoring and directing, which are also complementary in their occurrence.

3. Studies 2 and 3: the regulation process within CSCL contexts

Computer supported collaborative learning (CSCL) is increasingly being used in educational contexts. CSCL is defined as students working together in small groups and using computers and network technology to achieve a common goal, (Lehtinen, Hakkarainen, Lipponen, Rahikainen, & Muukkonen, 2000). CSCL is a learning approach that involves a much more active and constructive role on the part of learners and treats learning as a process of interaction and negotiation with others (Van der Linden, Erkens, Schmidt, & Renshaw, 2000). The approach is close related to socio-constructivist theories of learning.

The focus of these theories is on the development of individual cognitive skills within a social context and the social construction of knowledge via interaction and the conduct of joint activities. Via interaction with others, learners can become more self-regulative and gradually take more responsibility for the conduct of a task. More specifically, participants in CSCL activities must establish shared knowledge as part of their coordinated effort to perform a particular task (Littleton & Häkkinen, 1999). Although research in other areas has demonstrated the importance of self-regulative strategies for student learning (Artzt & Armour-Thomas, 1997; De Jong, 1992; Schraw & Moshman, 1995), research on such self-regulation within the context of CSCL tasks is still scarce.

There are several reasons to see self-regulation as critical for CSCL. First, CSCL requires students to work together without much teacher guidance, which places a heavier burden on the regulation strategies of students than more traditional didactic methods. Second, CSCL tasks are often complex, variable (i.e., there is no "right" or "wrong" answer), and only loosely structured. CSCL tasks clearly require such regulative activities as monitoring, planning, and evaluation (Artzt & Armour-Thomas, 1997). Third, nonverbal and social cues are largely lacking within a CSCL setting, which creates a need for more active and explicit regulation of the learning process. Finally, the members of a CSCL team are often in a position to monitor both their own learning and the learning of others and thereby potentially increase the effectiveness of the collaborative learning effort (Larson et al., 1985).

Text-based Computer Mediated Communication (CMC) within a CSCL environment provides a powerful medium to promote reflection on ideas (i.e., monitor learning) (Cohen & Scardamalia, 1998). The time delay and permanence of text-based CMC enable reflection on earlier stated information and allow individuals to "think before talking" (Veerman, Andriessen, & Kanselaar, 2000). Text-based CMC also allows for more precise expression than face-to-face communication because students have more time to think in an a-synchronic conversation. That is, text-based communication is more explicit than face-to-face communication and it is therefore easier to detect contradictions or conflicts in students' opinions.

Unfortunately, CMC lacks such social cues as nonverbal signals (e.g., eye contact, facial expressions, gestures), paraverbal signals (e.g., voice inflection, volume), and interpersonal signals (e.g., age, sex, physical appearance) (Adrianson, 2001). The lack of social context cues may hinder the collaborative learning process and the process of knowledge construction. And it is therefore recommended that not only ideas and knowledge be explicitly expressed during CMC but also social and affective statements in order to establish and maintain a secure and collaborative atmosphere. For regulative activities in CMC situations, it is also possible that a relatively greater emphasis must be placed on the collaborative process than in individual or face-to-face learning situations.

4. Study 2: regulation within a three dimensional CSCL environment

In the second study reported on here, the question of which self-regulative strategies students use while collaboratively working on a divergent task within a 3D CSCL environment was addressed. This collaborative aspect stimulated us to reconsider the coding categories we used in the first study.

4.1. Method

4.1.1. Participants

Six students who were either in 10th grade (i.e., 16–17 years old) or 12th grade (i.e., 18 years old) from two different Dutch pre-university high schools participated in the project "Virtual Exhibition: Andy Warhol." The students worked collaboratively at a distance in three dyads on an open task within a CSCL environment called

Active Worlds® (http://www.activeworlds.com). Participation was voluntary, and the students had never worked with Active Worlds® before.

4.1.2. Materials

Active Worlds® is a computer environment that allows users to create a virtual 3D world with houses, trees, signs, and other objects. Students thus "fill" the 3D world with different objects and "chat" with each other during this process (i.e., undertake synchronous communication). The presence of other students is visible via avatars, which are animated 3D characters. And a screenshot of the Active Worlds program can be seen in Fig. 3.

4.1.3. Procedure

The study lasted a total of four weeks. First, the participating students were instructed on how to use Active Worlds. Next, the students were instructed on how to collaboratively plan, design, and create a virtual exhibition. The students were given different pieces of textual information on Andy Warhol in order to create a positive interdependence between the students (Johnson & Johnson, 1999). The students

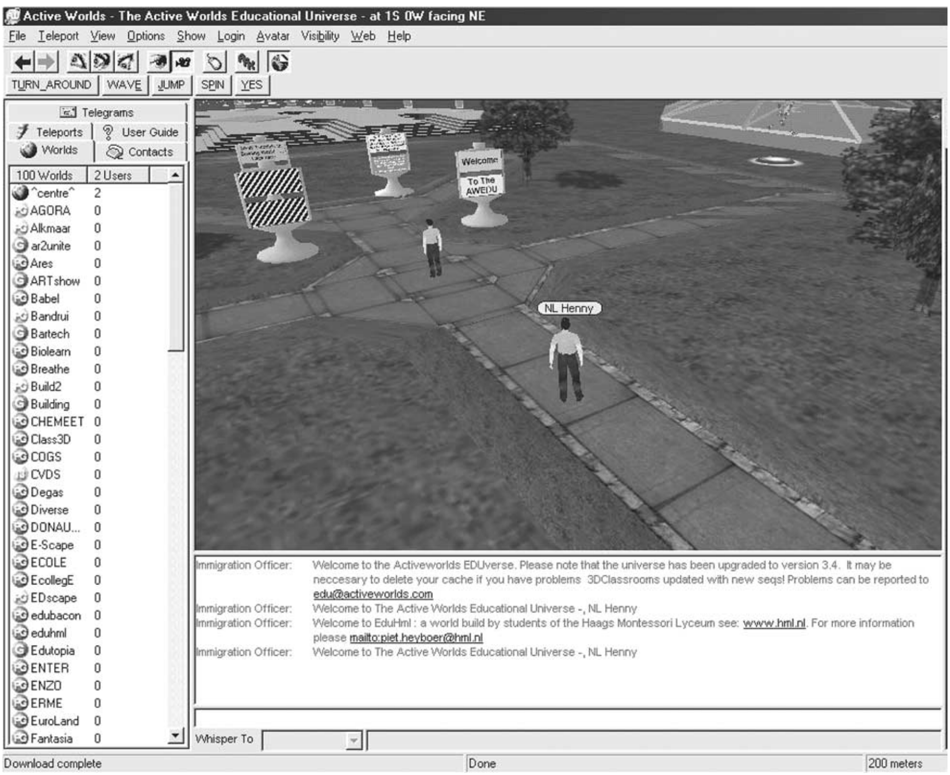

Fig. 3. Screenshot of the Active Worlds program.

from school A collaborated in dyads with the students from school B, that is, three dyads were formed with a tenth-grade student from one school and a twelfth-grade student from the other school. Dyads 1 and 3 consisted of one girl and one boy; dyad 2 consisted of two boys.

4.1.4. Task

The participating dyads were asked to create a virtual exhibition. More specifically, the students were told to exchange information about Andy Warhol, select up to ten works of art, explain their choice, and design, plan, and construct an exhibition on Andy Warhol. After completion of the virtual exhibition, one student from each dyad was required to give a guided tour of the exhibition to an art teacher. The students were only told the name of the student selected to give the tour a few minutes prior to the start of the guided tour. This was done to stimulate individual accountability (Johnson & Johnson, 1999) and to prevent any free-rider effects (Salomon & Globerson, 1989). The guided tour served as evaluation of the students' work.

4.1.5. Data

The empirical data consisted of the chat logs from the students during their online discussions. The chat logs were analyzed by first coding the written contributions. A written contribution could consist of one word or several sentences, and a single written contribution could be assigned more than one code depending on the number of meaningful units, with the meaningful unit delimited by a conversational turnover (Henri, 1992). The coding scheme consisted of eight categories of self-regulation and is based on the work of De Jong (1992), Veldhuis-Diermanse (2002), and Vermunt (1992). In Table 2, an overview of the eight categories of self-regulation and several indicators for each category is presented. In addition, a cognitive category – which refers to the cognitive processes that may occur during collaboration such as explanation and the asking of questions – and an off-task category were included in the coding scheme.

Two researchers coded the chat logs. Prior to the coding, the two researchers independently coded 536 contributions to determine the interrater reliability of their coding. The percentage agreement was found to be 72%. The Cohen's κ was .71.

4.2. Results

The three dyads successfully created their exhibitions in Active Worlds (see Fig. 4). The teachers who evaluated the work of the dyads and whether their task performance was sufficient or not used such predefined criteria as "Does the exhibition provide an overview of the techniques used by Andy Warhol?" and "Is there a relation depicted between Warhol's art and his way of life and the society in which he lived?".

The exhibition of dyad 1 consisted of nine works of art, which were all taken from the available database, and 18 signs with information for visitors, as can be seen

Table 2
Categories of the coding scheme

Category	Indicators
Orienting – preparation for the learning process and task performance	Discussion of task characteristics Discussion of CSLC environment Discussion of one's own knowledge and opinions
Planning – design of the learning process and selection of appropriate strategies	Suggesting how to carry out the task Deciding who is going to do what (task division)
Instructing – direction of fellow students	Instruction of other student Asking other student to carry out an activity
Grounding – trying to maintain a common ground	Asking other student for opinion about an idea or suggestion Calling attention to an idea or solution Posing of verification questions
Monitoring – keeping an eye on the learning process and task performance	Discussion of task progress Suggestion that a different approach be tried
Testing - checking whether learning goals have been reached	Checking for sufficient information Summary Improvement
Evaluating – evaluation of the learning process and task performance	Comment on the execution of the task Comment on the learning and collaboration process
Other regulative	Regulative statements that could not be classified in the categories above
Cognitive – cognitive processes relevant to collaboration	Questions Explanation of information to other student
Off-task – disruption or distraction	Joking Swearing Chatting with other visitors to the CSCL environment

from Table 3. In their exposition, dyad 1 provided a detailed overview of the development of Warhol's work. The exhibition of dyad 2 consisted of 11 works of art, with 10 taken from the database and 1 from the Internet, and 7 signs with information for visitors. No other special characteristics were observed. Dyad 3 was the most active of the three dyads: their exhibition consisted of 14 works of art, which were all taken from sources on the Internet, and 34 information signs. Furthermore, the students in this dyad expanded the exhibition hall beyond the original proportions and decorated the hall with several objects (see Fig. 4).

A total of 1546 codes was analyzed. As the findings in Fig. 5 show, grounding was the regulation strategy used most often with some 32% of all meaningful units coded as grounding. Another commonly used regulation strategy was monitoring (9.2%). The participating students appeared to keep an eye on their learning and task performance. Some 6.9% of the meaningful units reflected planning, which suggests that

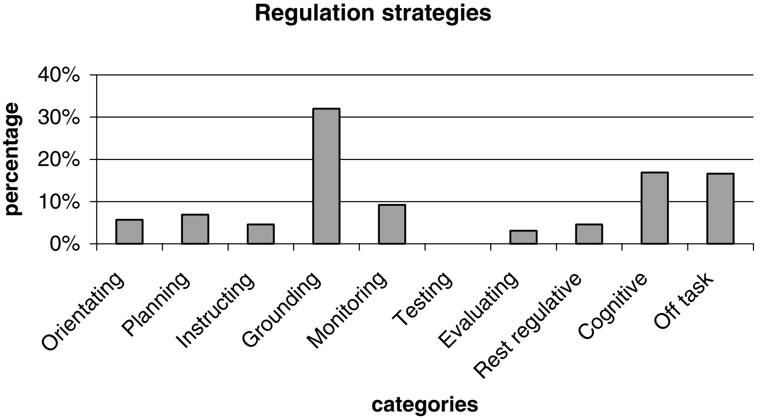

Fig. 4. Self-regulation strategies used in a 3D virtual environment.

Table 3
Characteristics of the expositions created by the three dyads

Sources	Dyad 1	Dyad 2	Dyad 3
Works of art	18	11	14
Taken from the database	9	10	0
Taken from Internet sources	0	1	14
Information signs	18	7	34
Special characteristics	Overview over time	No special characteristics	Extension exhibition hall and decoration

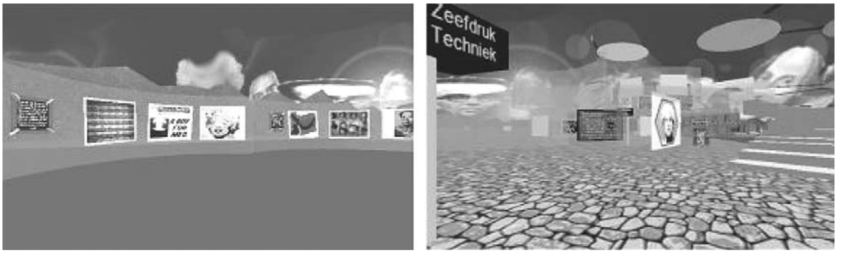

Fig. 5. Screenshots from the exhibitions created by dyad A (on the left) and dyad C (right).

the students felt the need to discuss the strategies to be adopted prior their use. Orienting, instructing, testing, and evaluating were used infrequently. Cognitive strategies were frequently used by all three dyads. Some 16.9% of all the meaningful units were coded as reflecting cognitive strategies. Finally, 16.6% of all the meaningful units was classified as off-task behavior.

4.3. Discussion

In general, the students devoted much of their time to grounding. In other words, they were very busy confirming that their partners understood what had been said (Beers, Boshuizen, Kirschner, & Gijselaers, 2004; Clark & Brennan, 1991). This high percentage grounding may have been caused by the lack of nonverbal and social context cues within such CSCL environments as Active Worlds (Bordia, 1997; Straus, 1996). That is, communication may indeed be more difficult with no social presence and a greater need for grounding therefore exist under such circumstances (Short, Williams, & Christie, 1976). Monitoring also frequently occurred, which shows that the students keep track of their task performance (Schraw & Moshman, 1995). The other regulation strategies (i.e., orienting, planning, instruction, testing, and evaluation) were relatively infrequent possibly due to the fact that the planning of the task activities (i.e., three virtual meetings and a guided tour) and the content of the collaborative meetings were stipulated prior to the conduct of the task.

In sum, the three dyads successfully created exhibitions within the *Active Worlds* CSCL environment (see Fig. 5). The exhibitions provided a good overview of the work of Andy Warhol. However, the data collected for this study involved only a small high school sample, which means that replication or extension using a larger sample is necessary to provide a more reliable and detailed picture of the regulation strategies used by students working on a complex but open task within a CSCL environment. Use of a larger sample of students may also allow us to link the use of particular regulation strategies to successful task performance. And in the end, it may be possible to determine which regulation strategies are actually required to perform well within a CSCL environment.

5. Study 3: regulation within an elementary school CSCL environment

In this study, the regulative activities and strategies of elementary school children working in a CSCL literacy environment are explored. The present study differs from the previous study in that the students did not work at a distance from each other or with partners who they did not know; the elementary students worked, rather, in their familiar classroom setting with classmates who were familiar to them. The students studied here were also younger than the students in the previous study, and their age therefore more comparable to the age of the students in the first study. The students in the present study also worked in a "shared space" but without the 3D elements and Avatars available in the second study. The shared space in the present study was much more text-based and had a more advanced knowledge-building facility than the Active Worlds chat facility in the second study.

The frequent occurrence of grounding activities observed in the second study raised the question of what might account for this: the collaborative learning aspects of the task, working at a distance, the 3D environment, and/or the students being older. The present study resembles the first study with its use of younger students and the second study with its emphasis on collaborative learning but not at a distance and not involving 3D elements. The three studies were not planned as a whole but carried out separately over the past few years. The first study was set up from the perspective of regulation while our "knowledge sharing" brought us, the authors, to the conclusion that post hoc examination of the data from the second and third studies from the perspective of regulation might also be insightful.

5.1. Method

5.1.1. Participants

A total of 28 Dutch sixth graders from a single elementary school participated in the present study: 14 boys and 14 girls (mean age of 11.6 years, SD = .57). The CSCL environmentused in this study was Knowledge Forum (KF), specifically developed by researchers from the Ontario Institute for Studies in Education (OISE) to support knowledge building via computer-mediated interaction (Scardamalia & Bereiter, 1992). KF is a communal database in which students' contributions (i.e., notes) are stored and students are thus able to read each other's contributions and respond to them by writing a so-called "build-on note." As in many other discussion forums, there is no pre-defined content for the KF. However, there is an integrated function for categorizing the written contributions to the KF in order to support reflection upon the argumentation and reasoning encompassed by the KF.

5.1.2. Procedure

Students worked a total of four one-hour lessons using 30 networked computers situated in two different areas of the school. The topic of the project was "horror stories," and the students used the KF to discuss the concept of horror stories. The purpose of these discussions was to familiarize the students with the genre of horror stories, to create common knowledge regarding this topic, and to make them aware of the different strategies used by authors to make a story scary and exciting to read. The project formed a regular part of the elementary school's sixth grade literacy curriculum.

5.1.3. Data

A total of 154 written CMC contributions were analyzed using sociocultural discourse analysis, which is an interpretive data-driven methodology to analyze the content and function of language and just how shared understanding develops within a social context over time (Mercer, 2000; Mercer, Littleton, & Wegerif, 2004). Within the context of the present study, such a discourse analysis allowed us to identify key themes without imposing a structured methodology or too many preconceptions and subsequently explore the regulative strategies used by the students during the relevant learning activity. The analysis of the interactions was realized with the help of computer-assisted qualitative data analysis software (QSR NVivo). Presentation of all the data and findings for this particular study would greatly exceed the scope and purpose of the present paper, and we therefore present only the data related to the students' regulative strategies.

5.2. Results

Analysis of the computer mediated discussions showed 98 of the 154 notes to contain passages of a regulative nature. We found strategies indicating an awareness of the collaborative process and strategies reflecting evaluation of certain content on the basis of the task requirements. The most common regulative activities were trying to establish or maintain common ground (62.6%) and evaluation of the content of other notes with regard to task requirements (22.5%). An example of an evaluative remark is: "... It's a pity your reason was so short. You could have written for example why the story is so scary and which other books the author has written and what the name of the author is." This student appears to be aware of the task performance requirements and the strategies needed to meet these requirements. Most of the evaluative remarks concerned notes written by others and relatively few evaluative remarks thus concerned the students' own written contributions (2.9%).

The students were found to put considerable effort into trying to establish common ground via their CMC notes. This was mainly done by addressing a note to a particular person (30.3%) or by explicitly stating their agreement or disagreement with a remark from others (28.4%). In accordance with Barnes and Todd (1977), we take formal expressions of agreement such as "We also think it is scary when your name is Scarychat and its Friday the 13th and suddenly he's at your door" to be indicators of the level of "collaborativeness" for a discussion. Expressions of disagreement such as "We think Buffy [the Vampire Slayer] is much nicer because exciting things are happening and sometimes it seems as if you go through it yourself" help to reveal discrepancies that exists in the knowledge and ideas of the different students, particularly when the expressions are accompanied by an explanation or reason.

Another regulative activity used by the students was the instruction of other students mainly in the form of suggestions to improve their contributions (6.9%). An example of such an instruction would be: "Could you please explain a tiny bit better why the film is scary in particular??? Because we are really curious about that!!!". Such self-regulative activities as monitoring, planning, and discussing were not used very frequently by the students. Just as in the second study, however, this may be due to the fact that the task was relatively well-structured and the students knew – or thought they knew – what was expected of them.

5.3. Discussion

The CMC interactions in the third study showed that students devote little effort to the monitoring of their own learning processes. They did, however, monitor the collaborative process and evaluate the learning process in terms of the group and task goals. According to the teacher, the students effectively and collaboratively discussed the concept of horror stories and successfully created common knowledge with regard to the topic. The teacher's focus on collaboration was quite apparent in the CMC contributions, which suggests that task requirements may be an important determinant of the regulative strategies utilized by students.

Relative to the second study, the CMC interactions in the third study did not show many grounding activities. The students were not found to attempt to establish whether their ideas had been understood by others or not. This finding may be explained by the fact that the students in the second study worked within a CSCL environment that allows synchronous communication (i.e., chatting) while the students in the third study worked within a CSCL environment that only allows asynchronous communication. The slower pace of asynchronous communication fosters greater explicitness in messages and thereby diminishes the need to check for a shared understanding and other grounding strategies (Wegerif, 1998).

In the present study, the students were found to evaluate and instruct other students. However, the instructions were generally stated very politely and efforts to state explicit agreement were also quite frequent, which shows the students to be actively attempting to maintain a pleasant collaborative atmosphere. Once again, this may be due to the fact that the teacher emphasized the collaborative process during evaluation of the lessons and/or the fact that the students were trying to show their awareness of the importance of maintaining a collaborative atmosphere. While the types of grounding encountered in the second study differed from the types of grounding encountered in the third study, it can be argued that the explicitness of the grounding efforts in both studies show the students to be very much aware of the limitations of CMC in terms of contextual cues and social presence (Barile & Durso, 2002).

The students in the third study rarely used such regulative strategies as planning and orienting. This may be due to the fact that the task was clearly defined and structured. The topic of discussion was also established a priori, and the goals of the task were stated explicitly. Furthermore, the students knew each other and were therefore familiar with the background knowledge of the other.

It should be noted that, just as for the second study, the data collected for the third study only involved a small sample of elementary school children. However, the goal of the present research was not to determine which regulative strategies are required for effective performance within a CMC learning environment but to simply describe and understand the regulative strategies and activities used by the students within this particular context.

6. Conclusions and general discussion

We can conclude that the regulation of learning activities occurs in almost every learning context. When the learning is regulated within an individual context, activities that direct the learning activity relate to student test performance. We did not examine this relation within a collaborative context, but it is obvious that some relation to student performance may exist. Within the individual learning context, the learning process accompanying a complex task starts with the directing of information-processing activities and gradually shifts towards more testing activities such as summarizing, hypothesizing, and checking. Only towards the end of the learning process, about 75% of the way, are more testing activities found to occur than information-processing and concomitant directing activities. The effects of directing activities at both the beginning and the end of the learning process are also monitored intensively.

Comparable to the individual learning context, monitoring, planning, and evaluation activities are found to frequently occur in the CSCL contexts as well. However, other regulative activities related to learning and thinking together were found to occur even more. In the second study, where the students collaborated at a distance, numerous grounding activities to establish and maintain common ground were apparent. In other words, when the conversation is less physical and more virtual, greater attempts are made to establish that the one interactant understands the "same" as the other interactant. In the third study, where the students collaborated via text-based CMC on a clearly defined and well-structured task, the students mostly monitored and evaluated each other's task performance. Very few self-regulative activities were found to occur as most of the regulation was focused on the collaborative process.

In sum, we can conclude that the process of regulation appears to be quite similar across various contexts although the exact nature of the regulation may vary for individual versus collaborative contexts (i.e., depend on the specific context, task goals, and social aspects of the learning environment). When participants are less familiar with each other and working at a distance from each other, as in the second study, the process of grounding appears to be more important; when people know each other, have greater physical proximity, and greater social contact – as in the third study, the process of grounding appears to be less important. Another determinant of grounding activities may be collaboration within a 3D environment as the participants must more or less agree upon virtual objects prior to their actual construction.

Further inspection of the results of the three studies suggests that regulation in general is important for both individual and collective learning. It is striking, however, that in all of the studies the students were rarely found to orient themselves towards the learning task. This does not appear to fit the phase model of Veenman (1993), but the reason may be quite simple: namely that the students were clearly informed about the task, the objectives of the task, and what was expected of them prior to the undertaking of the task and more detailed orientation was therefore not necessary. The fact that the teachers informed the students of the goals of the task and what to do appears to inhibit the undertaking of orienting activities. By varying the amount of information provided externally, thus, the motivation, need, and ability of students to orient themselves towards a task can be modified as should be done according to good strategy user models (Pressley 1986, Pressley, Snyder, & Cariglia-Bull, 1987). Alternatively, one may opt to let students do what most people do and simply get on with things without reading the relevant instructions or manual. A practical consequence of such an approach is that greater effort must be put into orienting, directing, and monitoring activities.

The negative relation between performance and the occurrence of directing activities we observed in the first study is probably due to the fact that more successful students probably need and undertake fewer directing activities simply because they know what they are doing and they basically know the effects of their efforts. More successful students have also been found to be better at monitoring their problem solving, judging the difficulty of problems, aware of the errors that they make, and capable of adequate time allocation than less successful students (Glaser & Chi, 1988; Matlin, 1994).

In closing, the results of the three studies reported on here all show that learning regulation need not be based upon just "good strategy" but on the specific requirements of the learning context, personal competencies, and the potentials and constraints of the more general learning environment. "The more regulation, the better the learning" should probably be replaced with "The more adequate the regulation in relation to personal needs and external constraints on the learning process, the better the performance." And in conclusion, it is clear that think-aloud procedures and multilevel modeling can give us greater insight into the process of learning regulation and the temporal dimension of this process in order to determine how adequate regulation actually proceed to perform well within a individual and cooperative learning. A model that in the end can function as a model for instruction.

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